Practical Applications of Space Systems

Supporting Paper 11

Costs and Benefits

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A Panel Report Prepared for the

Space Applications Board

Assembly of Engineering

National Research Council

PREFACE

In November 1973, the National Aeronautics and Space Administration (NASA) asked the National Academy of Engineering* to conduct a summer study of future applications of space systems, with particular emphasis on practical approaches, taking into consideration socioeconomic benefits. NASA asked that the study also consider how these applications would influence or be influenced by the Space Shuttle System, the principal space transportation system of the 1980's. In December 1973, the Academy agreed to perform the study and assigned the task to the Space Applications Board (SAB).

In the summers of 1967 and 1968, the National Academy of Sciences had convened a group of eminent scientists and engineers to determine what research and development was necessary to permit the exploitation of useful applications of earth-oriented satellites. The SAB concluded that since the NAS study, operational weather and communications satellites and the successful first year of use of the experimental Earth Resources Technology Satellite had demonstrated conclusively a technological capability that could form a foundation for expanding the useful applications of space-derived information and services, and that it was now necessary to obtain, from a broad cross-section of potential users, new ideas and needs that might guide the development of future space systems for practical applications.

After discussions with NASA and other interested federal agencies, it was agreed that a major aim of the "summer study" should be to involve, and to attempt to understand the needs of, resource managers and other decision-makers who had as yet only considered space systems as experimental rather than as useful elements of major day-to-day operational information and service systems. Under the general direction of the SAB, then, a representative group of users and potential users conducted an intensive two-week study to define user needs that might be met by information or services derived from earth-orbiting satellites. This work was done in July 1974 at Snowmass, Colorado.

For the study, nine user-oriented panels were formed, comprised of present or potential public and private users, including businessmen, state and local government officials, resource managers, and other decision-makers. A number

*Effective July 1, 1974, the National Academy of Sciences and the National Academy of Engineering reorganized the National Research Council into eight assemblies and commissions. All National Academy of Engineering program units, including the SAB, became the Assembly of Engineering.

of scientists and technologists also participated, functioning essentially as expert consultants. The assignment made to the panels included reviewing progress in space applications since the NAS study of 1968* and defining user needs potentially capable of being met by space-system applications. User specialists, drawn from federal, state, and local governments and from business and industry, were impaneled in the following fields:

Panel 1: Weather and Climate
Panel 2: Uses of Communications
Panel 3: Land Use Planning
Panel 4: Agriculture, Forest, and Range
Panel 5: Inland Water Resources
Panel 6: Extractable Resources
Panel 7: Environmental Quality
Panel 8: Marine and Maritime Uses
Panel 9: Materials Processing in Space

In addition, to study the socioeconomic benefits, the influence of technology, and the interface with space transportation systems, the following panels (termed interactive panels) were convened:

Panel 10: Institutional Arrangements
Panel 11: Costs and Benefits
Panel 12: Space Transportation
Panel 13: Information Services and Information Processing
Panel 14: Technology

As a basis for their deliberations, the latter groups used needs expressed by the user panels. A substantial amount of interaction with the user panels was designed into the study plan and was found to be both desirable and necessary.

The major part of the study was accomplished by the panels. The function of the SAB was to review the work of the panels, to evaluate their findings, and to derive from their work an integrated set of major conclusions and recommendations. The Board's findings, which include certain significant recommendations from the panel reports, as well as more general ones arrived at by considering the work of the study as a whole, are contained in a report prepared by the Board.**

It should be emphasized that the study was not designed to make detailed assessments of all of the factors which should be considered in establishing priorities. In some cases, for example, options other than space systems for accomplishing the same objectives may need to be assessed; requirements for

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*National Research Council. *Useful Applications of Earth-Oriented Satellites, Report of the Central Review Committee.* National Academy of Sciences, Washington, D.C., 1969.

**Space Applications Board, National Research Council. *Practical Applications of Space Systems.* National Academy of Sciences, Washington, D.C., 1975.

institutional or organizational support may need to be appraised; multiple uses of systems may need to be evaluated to achieve the most efficient and economic returns. In some cases, analyses of costs and benefits will be needed. In this connection, specific cost-benefit studies were not conducted as a part of the two-week study. Recommendations for certain such analyses, however, appear in this report and in the Board's report, together with recommendations designed to provide an improved basis upon which to make cost-benefit assessments.

In sum, the study was designed to provide an opportunity for knowledgeable and experienced users, expert in their fields, to express their needs for information or services which might (or might not) be met by space systems, and to relate the present and potential capabilities of space systems to their needs. The study did not attempt to examine in detail the scientific, technical, or economic bases for the needs expressed by the users.

The SAB was impressed by the quality of the panels' work and has asked that their reports be made available as supporting documents for the Board's report. While the Board is in general accord with the panel reports, it does not necessarily endorse them in every detail.

The conclusions and recommendations of this panel report should be considered within the context of the report prepared by the Space Applications Board. The views presented in the panel report represent the general consensus of the panel. Some individual members of the panel may not agree with every conclusion or recommendation contained in the report.

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INTRODUCTION

The plan for the 1974 Summer Study on Space Applications specifically directed the participants to seek practical approaches to the future development of applications of space systems. To assist with this task, the Space Applications Board selected as members of the Panel on Costs and Benefits individuals with backgrounds in business, financial, or professional economics. As a result of the Panel's work and its interaction with the other panels, several suggestions have emerged which the Panel believes can contribute to the development of improved cost and benefit analyses of space applications.

First is the development of an outline of the key elements that a financial professional would consider in evaluating the space applications program. These suggestions flow from extensive experience of Panel members in the evaluation of large investment positions in comparable high-risk technological projects. This pragmatic orientation has been combined with the analytical perspective of the economists on the Panel to demonstrate effective means of quantifying anticipated, but in many cases as yet ill defined, benefits accruing from the application of space-derived information.

No attempt has been made by the Panel to evaluate the potential benefit of "spin-off" technology that can be expected to result from the space applications program. This technology can be an important incremental benefit but was not considered to be in the mainstream of the investment decision-making process for operational space systems.

On the cost side of the equation, the Panel has outlined an approach which hopefully provides new perspectives in the development of a cost minimization philosophy for the implementation phase of the program.

Pricing of both the space transportation service and the output information (at various possible access points in the data stream) is a critically important issue of a successful space application effort. The Panel has developed a position which should be helpful in the resolution of this basic policy issue. The Panel believes that the organizational arrangements associated with the management of the space applications program will have strong bearing on the development of reliable cost and benefit analysis. Strong and effective leadership in the early development phase of the program is essential to gain user cooperation in the structuring of a coordinated program. In the implementation phase, effective cost control is also closely tied to effective general management of the applications program.

The space applications program, if fully implemented in its presently envisioned form, will require a governmental investment of roughly $11.3 billion, including $2.6 billion in launch costs. This investment represents a heavy commitment by any standard and clearly supports the need for appropriate cost and benefit analysis at various phases of the proposed application investments.

It is important to recognize that the total investment in the space program through 1991 could likely exceed $50 billion. Embodied in this total expenditure are broad programs designed to meet the objectives of the Department of Defense (DOD) and the scientific community. The Panel urges that every effort be made to utilize, where possible, the capability built for defense and scientific purposes to reduce the total investment required to implement the space applications programs considered in the present study.

A final element in the objectives of this Panel is to identify high potential applications for future cost and benefit analysis. The Panel has chosen four major problem areas which have been cited as improvable through the application of space-derived information, namely, food supply and distribution; energy sources; mineral reserves; and communication and navigation. As examples of the application of cost and benefit analysis techniques, specific illustrations have been developed in agriculture and maritime traffic.

THE INVESTMENT DECISION

PREVIOUS ANALYSES OF SPACE APPLICATIONS

The Costs and Benefits Panel has reviewed the Report of the Central Review Committee as well as the Panel reports which summarized the 1967-68 summer study.* We are in general agreement with the conclusions and recommendations of the Economic Analysis Panel.** This group devoted particular attention to costing problems in conjunction with the user oriented panels. It suggested some useful general guidelines for future benefit analysis.

The Panel has had neither the time nor the opportunity to review systematically previous cost-benefit (and comparable economic) studies of potential space applications. We have examined samples of such studies which are either complete or in draft form. A few members of the Panel are very familiar with the work done thus far and have participated in some of these studies.

It is our impression that the approaches thus far taken to evaluate the net benefits of space applications to the user activities represented by the user oriented panels at the 1974 summer study have been straightforward and conventional, relying heavily on the standard concepts and tools of economic analysis. We note that this type of analysis is not a science but remains an art form. There have been a number of differences in the detailed structure of the models used. As one would expect, the less speculative and more straightforward studies deal with those applications in which information produced from satellite sensing is closely comparable to information previously available from non-space sources. In such cases, one focuses directly on potential cost savings possible from the greater efficiency of space information gathering and need not be concerned with the usually more difficult issue of benefit estimation. (When one simply compares costs of producing the same information from alternative sources, he implicitly assumes that the existing information system has a positive net benefit. In some instances, since so much information is provided at no cost to users by government, it may be desirable to check this assumption.)

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*National Research Council. *Useful Applications of Earth-Oriented Satellites*. National Academy of Sciences, Washington, D.C., 1969.

**The Economic Analysis Panel of the 1967-68 study did not provide a discrete report; rather its findings were included in the *Report of the Central Review Committee* and in the *Summaries of Panel Reports*, pp. 57-69.

As far as the Panel is aware, there has been to date no attempt at the kind of comprehensive analysis required before a decision is taken to develop an operational space information gathering system of the type contemplated by some in the earth resources area.

Legitimate differences of view can and do clearly exist in evaluating a given cost-benefit (or other form of economic) analysis. In some instances an appropriate methodology may have been employed, although it is our general impression that this has not been a particular issue in the case of existing space application studies.

A much more critical aspect of such analyses has to do with assumptions made in the study. The assumptions are crucial, since in looking ahead at the potential benefits of producing a new kind of information in new form, the analyst must extrapolate from past and present experience. One is faced with the need to consider how very complex systems (e.g., agriculture) will absorb new information and modify behavior so as to produce efficiency gains. The success with which existing studies have made such extrapolations and incorporated institutional factors is subject to honest disagreement. Inevitably, a great deal of judgment is involved in forward-looking studies in such fields. The history of human ability to predict the economic and non-economic impact of significant innovations suggests that caution is necessary in undertaking -- as well as in evaluating -- such efforts. For this reason, we note with approval in some existing (or in-process) studies the use of alternative assumptions and of sensitivity analysis (in which the sensitivity of the results to the values assumed for the variables is examined).

We are aware of one particular source of difficulty in the space applications field: economists have not agreed upon a general method to measure the value of information. Economists have only recently begun to develop models which explicitly treat information as an input to productive activity in a meaningful and systematic way. This work is beginning to develop important insights and potentially can make a contribution to evaluating space applications where the major "product" is information. However, as yet, these models have not been developed in a form which permits direct and straightforward empirical application. Since it has long been regarded as proper for governments to use publicly controlled resources to produce and disseminate information at nominal or zero prices, the full costs of information production and utilization are not reflected in market prices. Thus, a readily available market-value measure of benefits expressed in dollar terms is not now available.

Existing studies demonstrate the problem of having to infer what people would pay for information, since an adequate and complete set of data from which to extrapolate is lacking. This deficiency should not be interpreted to imply anything regarding the Panel views on appropriate pricing policy for publicly produced information. No criticism is suggested concerning present policy which provides much information at no, or nominal, price to private (and other public) users. The point here is to emphasize the difficulty faced by benefit estimators in the absence of an existing market system for many of the types of information involved in potential space applications.

Concerning the Economic Analysis Panel recommendations of the 1967-68 summer study, two specific comments are in order: First, certain members of the present Panel dissent from the suggestion made by the 1968 group regarding the use of differential discounting rates.* The intent of the 1968 panel was to reflect different degrees of uncertainty regarding cost and benefit estimates, both with respect to each other, and at different points in time. Separate estimates of the reliability attached to estimates of each variable are a better way to handle differential uncertainty (e.g., by expressing confidence intervals around each expected value). (Present value estimates have a different purpose and require a single rate to permit comparability across studies. Members of the present Panel who question our predecessors on this point recognize that it is a controversial point among economists and that there is no "conventional wisdom" on which to rely.)

Second, the present Panel recognizes the reasons that the Economic Analysis Panel of the 1967-68 summer study felt it premature at that time to estimate costs internal to user agencies and private users. The Panel believes, however, that it is imperative that total systems costs be estimated at each stage in a program's evolution, including explicitly the three classes of costs excluded in the 1968 study. (The classes excluded in 1968 were user costs for training and changing procedures; user costs for data analysis and interpretation; and end user costs such as cost to a farmer for changing farming methods or machinery.)

REQUIREMENTS FOR FUTURE DECISIONS

The Panel believes its contribution to future cost and benefit studies lies in suggesting analytical approaches which more effectively cope with the high level of uncertainty associated with many of the proposed applications. In this context, the Panel has attempted to identify key elements and methodologies in private sector analysis of high-risk technological ventures with the hope that they will suggest new approaches to improved cost-benefit analyses of space systems for practical use.

Evaluation of Large Investments in New Technology

The principal elements (key issues) to be considered in evaluating large investments in a new technology are discussed in the paragraphs that follow.

> Specific definition of the technology advance: At the outset it is important to establish the known and the anticipated capability of information gathering in space. The degree to which this capability advances the current state-of-the-art is a particularly important factor. An explicit statement of the capability can provide the basis for identifying new applications and evaluating the utility of those already established.
>
> Very often a technologist will miss applications of high potential which are recognized when a prospective user develops an understanding of the capability.

*See *Summaries of Panel Reports*, p. 68.

Market potential: It is vital that the total potential market (end-user customer base) be built up from the application of the technology to specific end-use problems. Is the application directed at major problems and needs? This information can only be obtained after extensive interaction between the expected user and the provider of the product or service.

Market structure: Equally important is a clear understanding of how decisions are currently made in the potential market being considered. How many different groups have to be informed or educated in order to gain acceptance of new technology?

Pricing: The best test of the utility of a new product or service is determination of the price that the customer would be willing to pay to obtain it. Pricing estimates should not be made in a vacuum, but rather in carefully designed communication with the expected user.

Marketing overview: All of the prior discussion of market potential is focused on assessing the real market which might be available to new technology. Market assessment is clearly a critical element in the process of establishing benefits for a space application program. Commercial marketing research is by no means an exact science, but it has been developed to a highly useful art. Business spends large sums in attempting to maintain a clear focus on user needs to sharpen the focus of new technology introductions. These data and methodology are equally important to government planners.

Investment: In evaluating a new technology -- especially one that is capital intensive -- it is important to try to establish the total investment required to commercialize the technology. In addition to becoming the denominator in the return on investment calculation, the total investment figure raises another question. In the private sector, one asks "Is the total program financeable?" The same question applies in the government except that effort must be made to insure continuity of funding, with the assumption that the investment objectives will be met. It is very important to recognize that private companies will require assurance of continuity of data or services from space systems before they will be willing to make major commitments to their utilization. Another consideration of investment is how it will be staged. How much is required at the outset? These factors are related to the determination of the risk associated with the investment. The size of the investment should be the major determinant of the level of analysis required to support the investment decision for each of the three major stages in the evolution of space systems as identified by the Panel on Institutional Arrangements,* that is,

*Panel on Institutional Arrangements. *Practical Applications of Space Systems, Supporting Paper 10: Report of the Panel on Institutional Arrangements*. Report to the Space Applications Board, National Research Council. National Academy of Sciences, Washington, D.C., July, 1975.

the research and development, the transitional, and the operational stages. This issue and its applicability to the space applications program are discussed in more detail subsequently.

Operating costs and profit: The previous marketing analysis permits quantification of the anticipated revenue stream from forecasts of demand and price. The profit in the private sector or the net economic benefit in the public sector is obviously the residual after subtracting the operating cost for the period being considered. The entire issue of cost estimating and control is vital to successful realization of anticipated benefit and will be discussed separately.

Return on investment: The methodology of calculating a return on investment (ROI) has been well documented in the literature. Because of the long time span of the space applications program it is essential that probabilistic estimates of future revenue and expenditures be employed and that they be discounted back to the present. This concept is widely employed in government and the Panel feels comfortable with the 10-percent discount rate currently being employed by NASA. It is important to recognize that the utility of ROI analysis is not that it yields an accurate answer, but rather that the ROI model permits the decision-maker to evaluate the effects of variations in the key elements of the analysis and to build confidence that the program has a reasonable probability of competing favorably with other potential uses for the same funds.

Break-even analysis: Independent of the ROI calculation, it is important to make an analysis of alternative cost and revenue levels and of the effect of delays in the schedule for the introduction of the product on the break-even point for the project. Figure I presents annualized cost and benefit (revenue) estimates to illustrate the life cycle trend of the key elements. Break-even analysis is a useful tool for the decision-maker to evaluate the dynamics of the key ingredients in the investment decision.

Portfolio analysis: Since the space applications program in the research and development (R&D) phase is built up from a series of experimental applications utilizing what in many cases will be common equipment and investment, it might be useful to construct the ROI evaluation for the R&D phase on a total space applications portfolio. Because of the inherent uncertainty in the individual applications programs, the error in the total analysis can be reduced by calculating an aggregate return on the total portfolio. In a simplified fashion, the format of such an analysis is as illustrated in Figure II, with ROI being calculated by taking benefits less operating costs divided by investment.

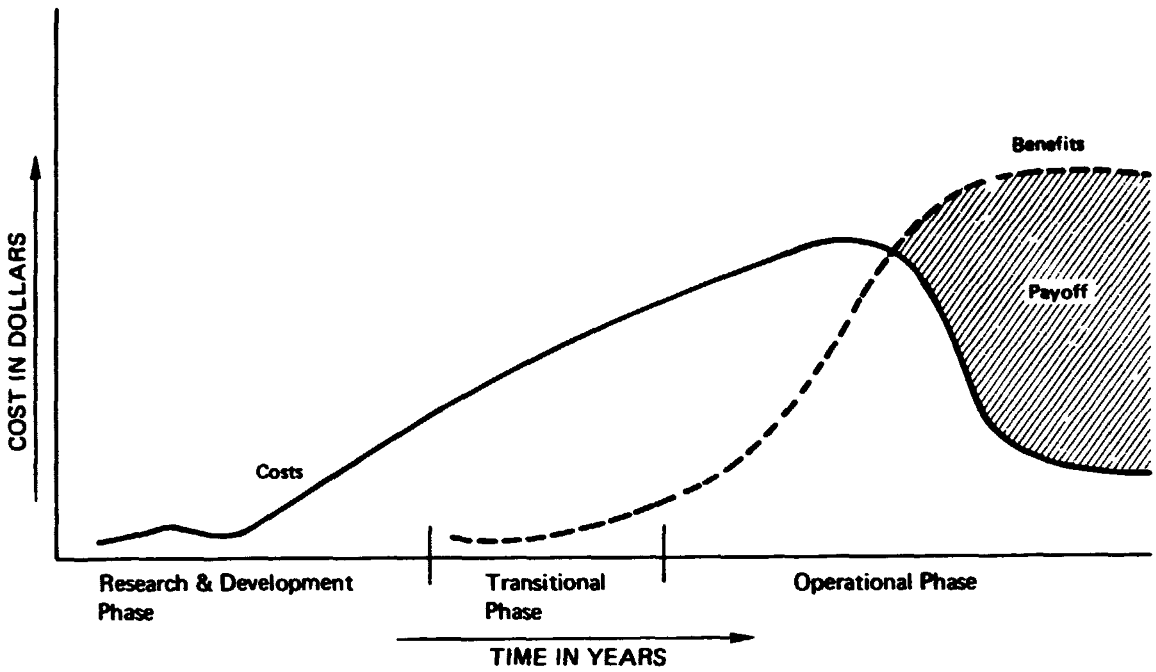

FIGURE I LIFE-CYCLE COSTS AND BENEFITS

Applications	Total Economic Benefit		Total Operating Cost		Total Investment	
	$	Probability	$	Probability	$	Probability
# 1						
# 2						
# 3						
etc.						
TOTAL						

FIGURE II FORMAT FOR RETURN ON INVESTMENT ANALYSIS AT THE RESEARCH AND DEVELOPMENT PHASE

In addition to an improved ROI calculation, this approach graphically demonstrates the economics obtained by getting maximum joint use of the investments which are common to several applications programs. This approach also has the benefit of keeping management focus on the total program and provides an incentive to follow the axiom of the business community to "turn off losers and double up on winners."

Elements in a Phased Investment Analysis

The various informational elements described above come into play at three investment decision points that occur at the beginning of the phases in the evolution of a space system, that is,

The research and development phase

The transitional phase

The operational phase.

At each of these points information will be gathered and analyzed in order to determine whether a project should continue into its next phase and, if so, the amount of additional investment required (see Figure III.) Of course, a cost-benefit analysis must be viewed as a process rather than the producer of a single point estimate for a "go/no-go" decision. As will be described subsequently, the method of analysis embodied in each cost-benefit evaluation varies across the three phases in the development of a space system. *It is very important that before embarking on any investment-decision process all parties (e.g., NASA, Office of Management and Budget and user agencies) to the decision must agree on the criteria to be used.* If this agreement is not reached at an early stage it must be expected that proposed projects will be subject to misdirected studies and delays which add extra costs and may lose benefits to potential end users. Furthermore, the objectives and alternative solutions of any project to be evaluated must be clearly defined.

Research and Development Phase: Prior to the R&D phase, a subjective investment decision must be made which will be based on a relatively small amount of information. Every effort should be made to establish a broad view of the economic aspects of the potential market to be served. In addition, an attempt should be made to gain a clear understanding of that specific market, for example, the potential users, utility of the product, current and potential competition, and other qualitative factors.

The requirement at this early stage is primarily to establish the logic of the proposed applications and the specific customer base to be served. Quantification is difficult and thus credible numbers are very difficult to arrive at for many applications. Nevertheless, there are analytical tools available to establish a broad range of values for the anticipated benefit. These tools should be employed. It is important that such information be developed and

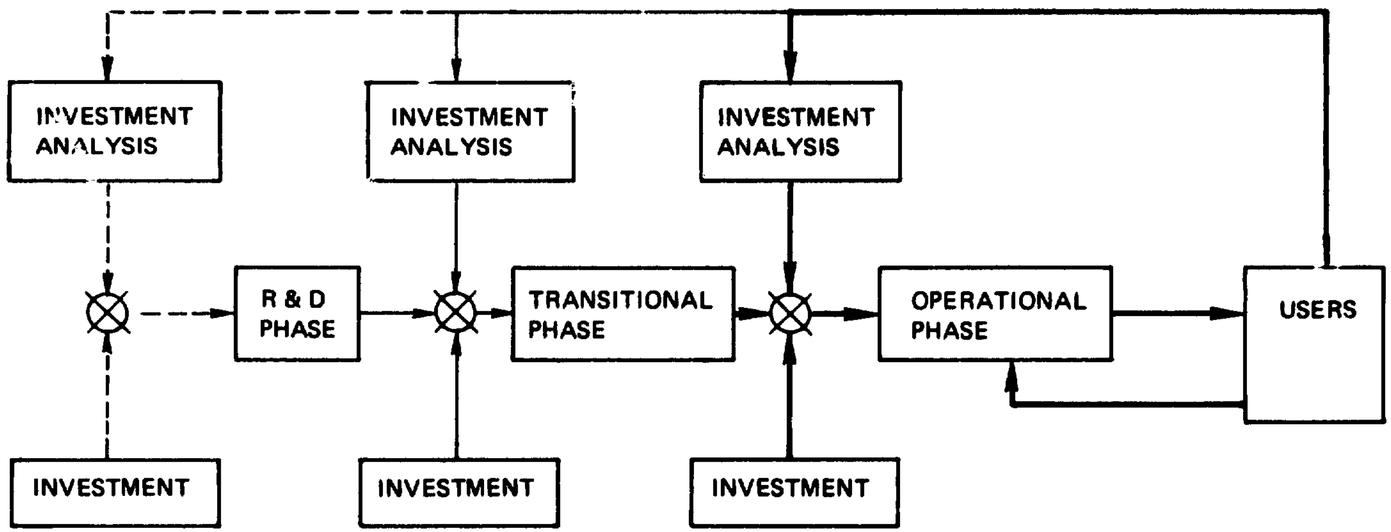

FIGURE III INVESTMENT DECISION PHASES

utilized at this point to serve as a baseline for future evaluation of the project and to help evaluate it in terms of others which are competing with it for R&D funds. In the case of promising ideas where little or no information can be developed at this stage, it is recommended that NASA have a small pool of discretionary funds to finance a few projects each year. Commercial R&D labs have such a pool of "blue sky" funds.

Transitional Phase: The investment decision point which takes place after the R&D phase and before the implementation of the transitional phase requires a more complete analysis of information. At this point, a more formal and detailed re-evaluation must be made of the economics of the project and its specific market to include an updating of the initial surveys made in these areas. Size of the market, competitive technology, user needs and preferences, and such must all be redetermined. At this juncture as much meaningful information as possible should be obtained from users because the planning and execution of the transitional phase will be best achieved when there is a large amount of this kind of input.

Concurrently, a study should be made of the potential users -- operational and management organizations -- in order to insure that the proposed applications are compatible with anticipated needs and thus provide an opportunity for maximum learning by users during the transitional phase. If a substantial amount of learning takes place in this phase, user informational input will be more accurate and serve as a firmer basis for evaluation of the project at its next decision point.

At this point, an attempt should also be made to ascertain the amount of potential investment which might be required throughout the remaining portion of the project development and, in addition, an estimate made of the aggregate benefit which would accrue to the users. Expected value techniques may be utilized to better determine the appropriate cost and benefit numbers. From these numbers a break-even analysis can be formulated.

Operational Phase: At the third investment decision point -- prior to the operational phase of a project -- the largest and most detailed amount of information must be studied and evaluated. As is shown in Figure III, it is at this point that a decision must be made with regard to the expenditure of the greatest amounts of investment funds. The previous economic and market studies must be refined and updated so as to include both information generated from the previous phases and new input from external sources. An overview approach should be taken by the group controlling the project and its various user applications in order to determine possible multi-user cost savings through the use of joint programs. A complete cost-benefit study should be made which will include detailed return on investment and break-even calculations as described earlier.

In addition to evaluation at each of the investment-decision points described previously, projects should be evaluated on a continuing basis using information developed in the project itself as well as that obtained from users and generated at the beginning of each phase. This continuous monitoring of information is especially important as a project progresses from the transitional to the operational phase. The constant flow of information and its interpretation will enable all of those involved to adjust their methods of evaluation and hopefully will result in an accurate and timely determination of the value of a project at a point prior to the expenditure of the largest amount of funds. The flow of information will also help to assure user participation in a project on a continuing basis.

COST AND PRICING ELEMENTS

After studying the cost methodology used in the 1968 summer study, the Panel agreed that suggestions of the 1968 study were still applicable in a broad sense, with a few modifying considerations based on the current situation. The major time-cycle categories for cost segregation were described then as: (1) applied research and technology, engineering and testing, (2) initial prototype development (equivalent to industrial "pilot plant"), and (3) full operational status. These correspond almost exactly to the phases designated in the 1974 study as research and development, transitional, and operational.

The costs for each category should be considered separately with full and detailed cost justification required at the beginning of each phase. The functional categories are best divided into space systems and data processing, distribution, and user conversion. Typical costs under these headings are as follows.

Space system costs:

Spaceborne hardware (sensors, data transmitters, attitude controls, power systems, etc.)

Launch costs to orbit (launch vehicle costs, launch facility costs, etc.)

Ground support systems (monitor functions, command and control of satellite, etc.)

Management and administration of space systems

Data processing, distribution, and user conversion costs:

Costs of ground stations to accept spacecraft information (imagery and the like) in raw form

Costs of equipment to process and organize the collected data into a format suitable to the needs of users*

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*It should be noted that depending on the capabilities of the user and the data processing facilities he has available, the user may wish access to the data at any one of several stages in processing of the data; this is sometimes referred to as "multi-tiered access."

Software costs for development of algorithms needed to process raw data (spectral analysis, change detection, characteristic signature extraction, image scaling, etc.)

Costs of converting the user's existing data handling process to use new information

Management and administration of the ground system

These categories for breakdown of total systems cost should be used for space applications analysis and projects.

Cost estimating is a fairly well developed discipline. When a new project is not too radically different from previous projects, rather accurate estimates are possible. In general, the best estimates are those based on past history with learning curves applied where appropriate. A note of warning, however, is appropriate today. Both the Department of Defense and NASA have felt the pressure of budget constraints in the last several years and have passed these pressures on to the industrial contractors who serve them. Such commercial equipment design concepts as "design-to-cost" and "cost-targeting" are starting to be extensively used in space and military hardware. Potential reductions in cost of 30 percent or greater are not unusual with this "new" methodology. Some intelligent accounting of the effect of these concepts has to be factored into the cost analyses which are used to assist decision-making. The effects of this approach can be seen, for example, in the difference between the currently projected costs of the space shuttle and the originally projected designs and costs. Since the ratio of costs to benefits can be improved markedly by lowering costs, the next section covers a few of the Panel's thoughts on cost minimization.

Cost Minimization

Minimizing the costs for space system hardware and software must be a key objective for all the groups involved in these programs. In any complicated system, the decisions which have the most impact on total cost are the earliest decisions. As the system evolution progresses, the options for change to lower-cost alternatives are decreased as the costs involved to make the change often cancel out the savings. System analysis, preliminary design, and cost trade-off analyses should, therefore, be done in detail and then reiterated several times during the system conceptual stage. Competing studies with cost as a yardstick can be very useful at this stage. Maximum use needs to be made of already existing designs. One of the most common mistakes in developing a new system is to make the whole thing new even though only a portion really needs to be new. Both program risk and cost are a direct function of how many new "fields" one tries to "plow" simultaneously. Considerable management discipline is required to control this design process, but the savings are well worth the effort. It is questionable in the minds of the members of this Panel whether NASA has practiced this discipline as much as it could have, particularly with regard to the use of hardware developed by the DOD. The syndrome referred to as "NIH" (not invented here) exists in both organizations. The shuttle design philosophy removes one of the main excuses that has been used for unneeded redesign in the past -- namely, "it won't fit" in the spacecraft. The Panel believes that NASA management should direct particular attention to optimizing this advantage, and force its technical groups to abandon "change for change's sake."

Of course, modular design approaches, using as much standardization as feasible, should be utilized. NASA has focused on this approach in most of its scientific and applications satellites in the past few years with good results. Various branches of DOD also have aggressive programs for "building block" standardization, and NASA engineers should keep abreast of what is available from DOD and should maximize their use of DOD-developed hardware systems.

In addition to this emphasis on common use of hardware, standardization between user requirements should be pushed. Such standardization not only would bring economies of multipurpose payload designs but also would significantly lower software and data handling costs.

Several new factors in payload cost have been introduced with the advent of the shuttle program. The lessening of constraints on volume, weight, and power consumption and the option of having a person help carry out the experiments should make possible large reductions in experimental payload costs. These savings have the advantage of lightening the initial (front-end) costs on speculative experimental programs and deferring the costs of a final operational system design until basic concepts are proven. There is not only a direct cost saving here, but perhaps a more subtle point is that programs which do not require such a large investment to check out feasibility will be easier to terminate if the results are poor or marginal.

Any discussion on cost minimization would be incomplete without covering two of the most insidious cost growth factors, inflation and program deferrals ("stretch-outs"), both of which are generally beyond the control of a program manager. Labor cost estimates are generated originally in man-hours and then converted to dollars at current or projected man-hour costs. This procedure puts a squeeze on fixed dollar allotment programs when the inflation rate exceeds prediction. Its effects have been used unfairly to criticize program overruns and unrealized cost objectives. With today's exceedingly high and unpredictable inflation rate aggravating the situation, NASA might be well advised to keep both program cost predictions and program execution costs in equivalent man-hours both for keeping track of and displaying to others how well they did in estimating and controlling labor expenditures.

With the combination of budget pressures and inflation continuously lowering the man-hours per year that NASA can finance, there has been a resulting tendency to stretch out programs. This delay not only aggravates the "apparent" cost problem (in dollars) by pushing work off into higher inflation years, but it causes a very real (and significant) effect on total man-hours required -- particularly on programs that are already well under way and are based on a shorter, more optimum schedule. The benefits that NASA space applications projects offer can perhaps be deferred, but inefficiencies caused by stretch-out are a waste of public funds. Hardware programs should not be started unless there is full determination and long term fund commitment to carry them through on the original schedule. A smaller number of total programs may be called for.

Pricing

It may be expected that there will continue to be a need for NASA to "sell" hardware development and spacecraft launching services to other agencies and private industry. Attention to a rational pricing policy is therefore needed. In the past, pricing policy has served only to reimburse costs incurred on a particular project or launch. The price was set equal to incremental costs incurred; no additional charge was levied for "amortization" of previously expended R&D funds. Since NASA's mission is to provide R&D which will benefit the whole nation and since the fruits of this research are equally available to all, there seems to be no rationale to call for any recovery of such "sunk investment." The argument might be made that such investment recovery would be desirable to help finance further R&D, but this concept is not consonant with NASA's role. Further, once an R&D investment has been spent, the greatest economic good from the results occurs when everyone has use of those results at incremental costs caused by his use of the service. Typically, facility costs which vary with the volume of work have been included as incremental costs at some equitable amortization or lease rate. The Panel has no disagreement with this previous NASA policy.

The shuttle, with its large multiple payload capability, opens up a whole new class of pricing problems, however, which needs to be addressed. Since several groups may be sharing the costs of a single launch, an equitable multi-term formula needs to be derived. Ideally, the terms in this pricing formula should track as closely as possible the incremental costs incurred for that factor. Overall, the pricing should be structured so as to encourage, as nearly as practical, a full payload for each shuttle launch.

Shuttle pricing policy could have purposeful or inadvertent results such as acquiring new customers, limiting number of customers, giving preference to certain classes of customers, "squeezing out" competitive launch systems, etc. The pricing policy selected to accomplish NASA's overall objectives may be one of the most crucial decisions on the shuttle. The wrong pricing policy could well ruin the whole system. A careful study of, and comparison with, the railroad pricing system may be in order as a prime example of how *not* to proceed. Other considerations are:

The policy should be structured to avoid requiring NASA to provide launch services indefinitely for operational space systems

The system should not significantly interfere with the free market interplay of competitive forces

The economies of scale (learning curve) that give lower costs in the future should be shared with the shuttle customers

There should be some reasonable flexibility for change in policy as more operating experience is gained.

NASA may choose to underwrite some launch costs on early shuttle flights to attract early customers and to offset somewhat the risks inherent in early flights of a new vehicle. That is, the underwriting may appear as a development cost. It should be clearly identified as such and not hidden in some way as to mislead the shuttle user as to his eventual operational costs.

Similar questions arise in considering the price placed on sale of the data which emanate from all the earth resources satellites. Clearly these data should be made available to all and in any form readily available from the data chain (i.e., from the telemetered radio frequency signals to data in digital form, to partially processed data, to fully processed data) in order to give maximum flexibility and hence maximum utility to potential users. Pricing of these alternatives requires careful study, however. Prices which are based on incremental costs for providing such "data taps" should be considered prime candidates. There will be arguments that the most economy will be realized from one massive digital data processor for all users and hence only fully processed data should be sold. While this may eventually prove to be true, it should be tested in the marketplace first by letting all varieties of data reduction exist. Certainly the eventual economy of such data handling will depend on the development of more clever and more efficient software aimed specifically at a certain set of user needs. Experience suggests that small, young, entrepreneural companies will do this development best, particularly in the early stages. Pricing policy might appropriately be set to encourage such companies but in no case should it be shaped to discriminate against them.

BENEFIT ESTIMATION

BACKGROUND

Defining and measuring benefits is the single most difficult challenge in assessing the merit of programs of the sort under review by the user-oriented panels of the 1974 Space Applications Study. In evaluating particular characteristics of space applications being considered by the user-oriented panels, we note that the most important type of output, insofar as benefits are concerned, is *information*. The central point to be made about the benefits produced by information is that they arise if, and only if, the information changes the economic behavior of one or more individuals or organizations. Information has no economic value unless it is used and positive change occurs.

Thus, we must go through an often complex chain beginning with data acquired by a space sensor to reach a point where we can attempt to estimate a benefit appropriately attributed to the acquisition of data. That end point will find some economic "actor" behaving more effectively because of the space-derived information made available to him.

ESTIMATION ELEMENTS

There are usually three possible approaches to the specific evaluation of benefits from federal government programs. These are:

1. Benefits in terms of cost savings (equal capability analyses), where the capability of each alternative is similar, and the goal is not questioned.

2. Equal budget analysis, where each of the alternatives considered is allowed to spend, in the operational phase, the same budget. Thus, in addition to the cost savings for the same service level, a value (benefit) has to be measured for the added service of the same kind made possible by lower operating cost systems.

3. New capability benefits, where the service provided by the new systems is different in kind from anything now provided, such that, in principle, analyses of type (1) or type (2) cannot be performed.

Figures IV and V illustrate the scope of each type of analysis. Each analysis has to be goal (operations) oriented. Each type of analysis may be applicable at different phases of the investment process or for a different type of application (investment).

Also -- and most important -- in any one of the above types of benefit analyses, the goals and the capabilities required or promised need clear, precise definition, since these will form the basis for any reliable investment analysis, whether public or private. Often, particularly in the early stages, the "benefit" of benefit analyses may be precisely to force the decision-maker to a clear definition of capabilities needed.

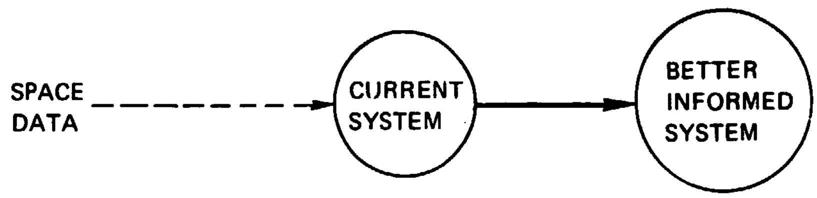
Finally, if alternatives exist to achieving the same or similar objectives, these need equally detailed definition and analysis.

SELECTING THE PROPER METHOD OF ANALYSIS

As indicated previously, a benefit accrues only when positive change is induced by the utilization of the information from space. We must then ask a crucial question, i.e., "Who can benefit from this new information source?"

The answer must be framed in specific operational terms, that is, specific end users, or specific end use problems, or specific new opportunities made possible by the availability of this new information source.

The benefit estimation process then becomes one of estimating the change made possible by these data. Schematically, the change can be represented as:



The analysis required to estimate the value of this information stream focuses on four key questions:

How "large" is the current system?

How fast would it grow without space data?

How fast can it grow with space data?

Are non-growth factors, such as lower cost of information or improved distribution, significant?

The last question suggests an important element of the analysis. The investigator should seek to identify the total gain possible from the use of new information. At the outset no attempt should be made to reduce this theoretical potential benefit by virtue of any organizational constraints (user or provider).

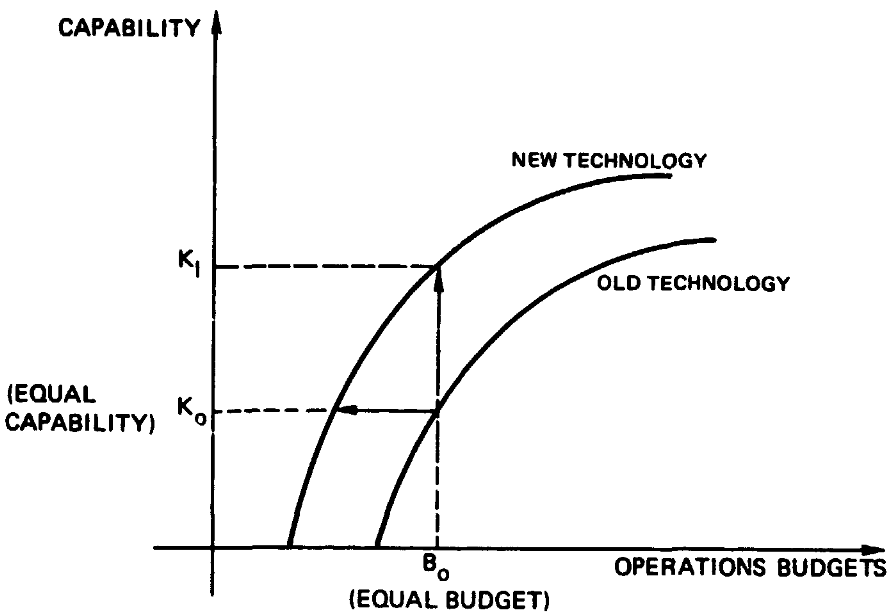


FIGURE IV SCOPE OF BENEFITS WITHIN COST-ORIENTED ANALYSES

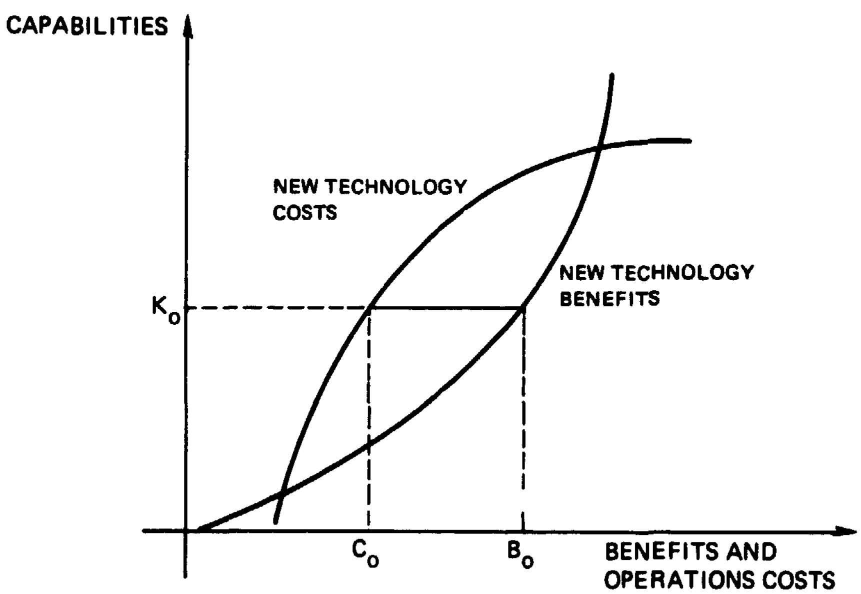


FIGURE V SCOPE OF COST-BENEFIT ANALYSES OF ENTIRELY NEW CAPABILITIES

The first question (How large is the current system?) is a crucial determinant in the choice of analytical methodology required to quantify the benefit. In simplified terms, it is useful to determine whether the benefit accrues in a single discrete sector or whether it is felt across multiple sectors of the national or world economy. We believe that the analytical tools needed to evaluate benefits are different for each area and will discuss them below.

SINGLE SECTOR ANALYSIS

In reviewing the space applications being considered by other panels in the present study, the following ones appear to be examples of those having their greatest impact on a single, or at least a limited number of discrete "end user" sectors:

Extractive resource exploration

Marine navigation

Commercial communication

Biological processing in space

In each of these applications, it is possible to quantify the expected benefits of new information via an aggregate macroeconomic analysis, that is, a sector-specific econometric model to determine the value of R&D expenditures on the communication sector. This "top-down" analysis can provide a useful benefit estimate.

On the other hand, when the new information affects a limited user base, it is possible to employ conventional industrial market research methods to establish the current size and growth rates for the user sector being evaluated.

For example, in the case of oil exploration, industry data are available to identify the total current expenditure on exploration. The first question above concerns the size of the current system. The industry could also supply data which would roughly establish the rate of growth of the current system, namely, the value of new resources expected to be discovered as a consequence of planned future exploration expenditure. This information yields the growth rate without space data.

The growth rate with better information from space can only be developed through detailed interaction of the appropriate space technologists with experienced petroleum geologists and petroleum economists. Their task would be to establish the value of incremental new reserves which could be found, in the same time period, as a consequence of improved drill site selection using information from space.

In the initial stage of formulating a benefit estimate in a particular application program, the focus of the analysis should be on identifying the maximum gain possible. Consequently, there must be an effort to creatively evaluate the potential utility of this new information. As data are provided from the space system and experience is gained in their use, the initial benefit estimates can be refined.

The same type of analysis can be applied to other natural resources subject to improved exploration as a result of space-generated geological data. The total benefits can then be aggregated and measured against the cost of providing this information.

MULTIPLE SECTOR ANALYSIS

While the following space applications could have an impact on a single user sector, they also are examples of those which can affect more than one discrete sector:

Weather and climate

Environmental quality

Inland water resources

Agriculture

Land use planning

When applications have potential for providing benefits to a number of different users or sectors in the economy, it is more difficult to quantify the aggregate magnitude of the benefits.

In the case of benefits derived from public services and provided to multi-users at no charge, or where charges have little or no relationship to the amount of the service consumed by the various users, one can attempt to evaluate the benefit on the basis of an estimate of a "shadow" price for the service in question: "What would people pay if such a service were sold?"

This is more readily done where goods or services comparable to those provided free or at nominal price by government are also sold by private producers (for example, recreation services such as camping facilities). Estimates of the benefits provided by the National Park and Forest Servic have been derived, based in part on the prices people are willing to pay fo comparable commercial facilities.

Where there are no comparable services and the users are not easily identifiable, as is the case with applications which could lessen traffic congestion or control pollution, then one must look at the extent to which services provided by space systems are or could be directly responsible for a positive change in the degree or severity of the condition. When the degree of improvement has been assessed, it is then necessary to identify the users who benefit from the change. In many cases, these benefits may have a broad socioeconomic impact and therefore they may not be easily quantifiable. In this event subjective estimates as to their ultimate value will have to be made.

ORGANIZATION AND MANAGEMENT*

Inherent in any investment study is a review of the organizational structure and management concept, intended to support that investment, to see that it is adequate to generate the proposed return.

The Existing Structure

As to space applications, it may be expected that NASA will operate the space shuttle vehicle and services and that it will continue to operate those expendable launch vehicles which are programmed into the mid-1980's and which could continue to be utilized should economy of launch or timing of mission dictate. It is assumed that NASA will operate the experimental satellites. Beyond these points, management and institutional responsibilities for space systems intended for practical uses are not yet clear.

The Opportunity

There is at present no designated organizational entity responsible for coordinating, integrating, implementing, and managing the multifaceted potential space systems.

These potential systems include satellites and ground systems to acquire, interpret, and transmit data to large groups of potential users. A one-for-one relationship between the user and the data system does not exist in most cases. To meet user needs, sensors must be developed; sensors and support systems must be combined into experimental hardware; the hardware must be integrated into a total mission plan involving multipurpose shuttle missions and/or expendable launch vehicles; ground systems must be developed to receive the data and to translate it into the user required format; transitional programs (to demonstrate actual operation of the system) and operational systems must be implemented.

These activities require an organization structure with a high degree of sensitivity to user needs, an ability to develop effective user working groups, and a capability to establish policy, particularly as to cost, price, and funding requirements.

The Function

The function to be performed may be described as that of a "general manager" of space systems for practical applications. The general manager would coordinate the user requirements, market the technological capability, conduct the necessary market research to expand the user market, and manage the development of necessary economic information to satisfy the investors.

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*See also, *Report of the Panel on Institutional Arrangements, Supporting Paper 10, Practical Applications of Space Systems.* Report of the Panel on Institutional Arrangements to the Space Applications Board, National Research Council. National Academy of Sciences, Washington, D.C., 1975.

The Investor

At this time, the federal Office of Management and Budget, perhaps because of impending fiscal constraints and perhaps also sensing a pyramiding of uncoordinated requests for space applications funding, has directed that all new programs for fiscal year 1976 in the space applications area be subjected to cost-benefit (investment) analysis. *It is the Panel's opinion that this request cannot be effectively responded to in the present uncoordinated structure.* There is need to designate a "general manager" responsible for satisfying this requirement by effective implementation through user working groups, including the private sector.

The Cost-Benefit Requirement

The need for cost-benefit (investment) analysis should be apparent from Figures VI and VII. These figures also illustrate the need for an applications general manager. Figure VI depicts today's situation, where uncoordinated multi-agency, multi-idea requests are being generated far in excess of dollars available for applications programs. Programs are being approved or denied on a judgment basis within dollars available without a specific value discriminator. Figure VII depicts the same idea generation, with agency requests coordinated among agency, user, and general manager, filtered through an economic discriminator, and rank ordered, leading to approved applications having the most economic benefit.

It is conceivable that proper utilization of the cost-benefit or discriminator technique could result in increased investment for applications.

The Agency

The role of the NASA Associate Administrator for Applications should be expanded to include the responsibilities of general manager in the early stages of all applications. The general manager's role should be continued through all phases of any given application, but for the operational phase the role should be assigned to the agency responsible for the operational system. The general manager should execute the functions described herein and should establish goals and missions for all user organizations.

In assuming the general manager role, it will be essential that NASA establish a strong service relationship with all users (including the private sector) for:

Applications planning

Experimental program technology planning and coordination

Costing and/or pricing of the service

Determination of who pays for what

Data dissemination policy

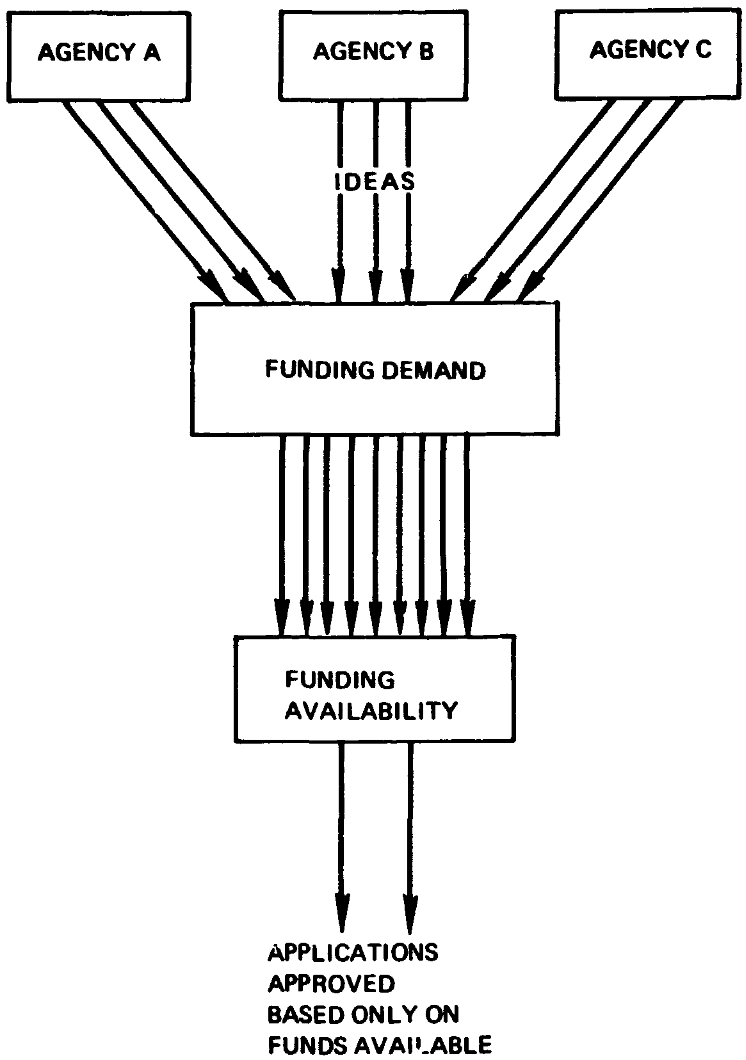

FIGURE VI PRESENT FUNDING METHOD

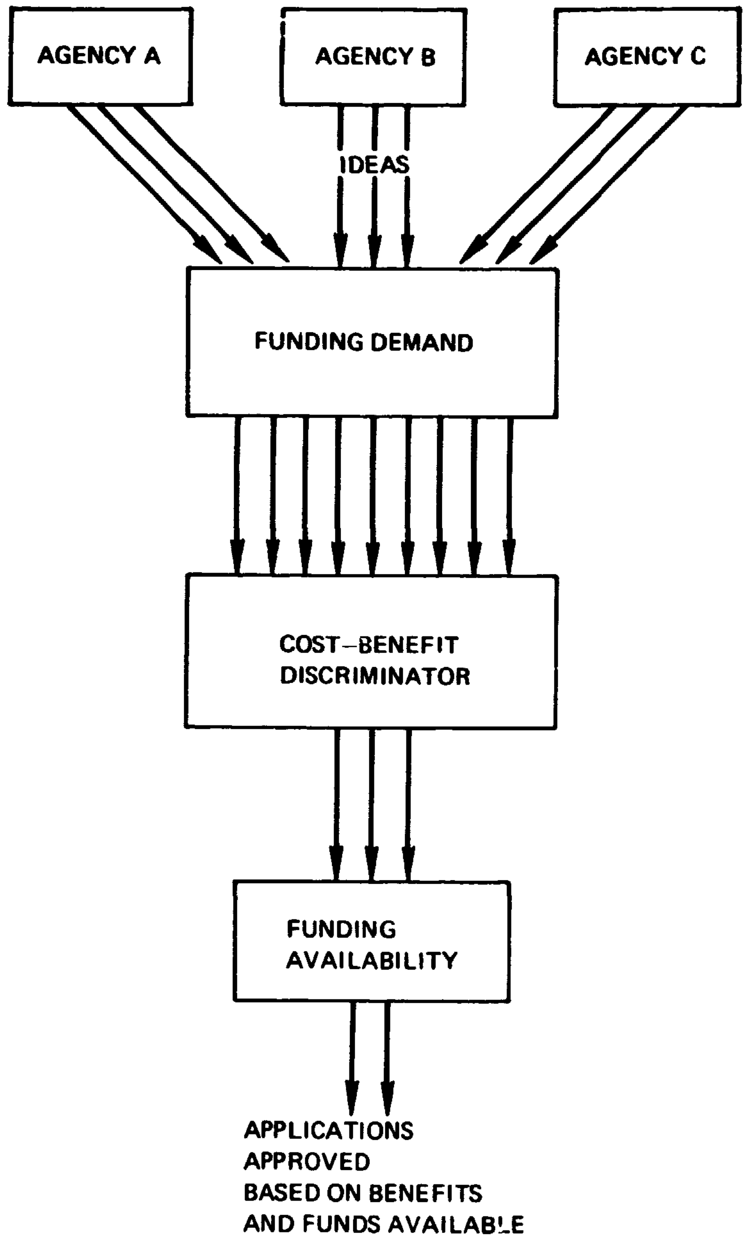

FIGURE VII PROPOSED FUNDING METHOD

Developing a policy for commercial investment related to continuing government investment.

It should be recognized that NASA, in the role of general manager, need not and should not be staffed to do the total applications task. NASA should, however, develop the capability for systems applications in the areas of requirements planning, market research and development, and socioeconomic analysis and should provide this capability as a service under the guidelines developed.

This system should result in clearly delineated goals (including cost-benefit) and missions, including timetables for all major organizations and should provide the proper tools and alternatives to develop fully space applications.

CANDIDATE PROGRAMS FOR FURTHER STUDY OF COSTS AND BENEFITS

The Panel, in reviewing previous studies of practical uses of satellites, was struck by the fact that most of these tended to be driven by the available capabilities (or future projections of same) rather than by the need. That is, there was a "solution" looking for a problem to solve. While this viewpoint is useful, a perhaps more fruitful approach is to start with key needs which are considered to have very large economic impact in the future and then to see how space derived developments can help. This kind of focus is one that a user community would have applied to previous studies, as opposed to that of the technology developer, who quite naturally sees the driving force as a new technical development.

The Panel recommends that broadly based cost and benefit studies be made in the use of space systems as applied to the following four key areas: food, energy, mineral resources, and communications and navigation. The basic advantage that permits space systems to make specific and important contributions is their global capabilities. Economic problems and opportunities in these key areas are recognized to be worldwide problems, rather than solely national or regional problems. This interdependence among countries and among problem areas (energy and food, e.g.) requires worldwide, timely and accurate services, information, problem recognition, and monitoring. We may not prefer these developments, but they persist.

The same capabilities of providing services and information are also useful, of course, to individual regions, countries, and areas within countries. It is, in fact, these benefits that largely motivate national space application efforts. It is the global capabilities that the Panel believes will be the source of the true ultimate benefits of space system applications. However, the problem becomes one of concrete specification: how can space systems help in any one of these areas?

Clearly, the contributions of space systems to economic problem solutions on earth are complex. To be assessable, the contributions must also be direct. The contributions that space systems can make have to be considered in a systems context, where many and probably most of the activities are carried out on the ground. Space systems are complementary, but sometimes decisive, components of these earth-based activities.

One type of contribution, increased production of goods and services, is easily understood. The purposes of economic assessment in this case are chiefly to verify the claimed technical performance, measure the output, and assess the demand for the added (or new) product or service, making allowance for the price level of the product offered in comparison to its closest competition. Such an assessment is not easy, but it is accepted as "real," not only by the innovators but also by the public, the executive officers of government, and the U.S. Congress.

But how can any value be arrived at for space sensing where the total quantity (e.g., of wheat produced) is not changed but distribution and planning are improved? This second type of contribution where total physical quantities stay the same is much more difficult to comprehend and to accept, yet it is the consensus of the Panel that it is precisely in this area where many of the economic opportunities occur today, and also where space systems can make lasting contribution: to gather needed information on a global basis.

FOOD

The demand for and the supply of food today is in a delicate balance, both domestically and worldwide. Projections of these two factors over the next few years and decades have been made elsewhere, but the seriousness of the worldwide balance of supply and demand in food, by crop, is generally accepted.

In the fall of 1974, a worldwide conference on food problems was scheduled by the Food and Agriculture Organization of the United Nations in Rome. However, to formulate short-term or long-term food policies, domestically and worldwide, one ideally would have to know what the facts are, worldwide, in a given month or even in a given week. For example, if the establishment of a domestic, regional, or worldwide food fund is to be seriously considered, it is advisable to know what size inventories exist, and what influence on these inventories results from continuously changing conditions in climate, acreage, management practices, crop conditions, agriculture policy decisions, opening of new lands, and progression of agricultural calendars worldwide, region by region, country by country, province by province. It is only when we know where the shortages are, when they are likely to occur, and the extent of the shortages, that we may proceed to distribute the resources from areas of surplus to areas of shortages either through world market price mechanisms (supply/demand) or through government policy decisions in terms of large scale, often long-term trade agreements. This process, either that of the market place or that of inspired government policy, is helped by -- and often only possible with -- accurate, timely information, not only on one's own food resources, but also on those of every other major region.

The worldwide interdependence in food problems shows up in unexpected areas. For example, the drastic decline in the anchovy catch off Peru in 1972-73 had a major impact on the availability of fishmeal for animal feed, which drove up prices for soybeans (a substitute) in the United States and, in turn, led to a temporary embargo on soybean exports to Japan with ensuing adverse effects on Japanese diets and living standards. In the agricultural case study example discussed in Appendix A of this report, we will mention the present precarious worldwide balance in food grains. Some of the information needed to cope with this problem is clearly not available in reliable form from present sources.

Information gathered from space will not eliminate likely food shortages, at least not now, but it will help timely decisions on a worldwide basis to overcome anticipated shortages before they lead to large-scale starvation in whole subcontinents. These events may occur with or without better information, but it seems clear that these problems can be significantly alleviated, if not eliminated, by adequate worldwide information.

Some of the measures being considered (e.g., a $20 billion food grain fund) involve inventories which clearly can only be built up and then distributed with the help of a worldwide information system. This $20 billion worth of food grains, for example, would have to come from somewhere, yet stocks are depleted at this time. The amount of grain that $20 billion will buy is largely determined by when, where, and how much is bought by the fund. We are talking here about 100 million metric tons of food grains, whereas the "Russian Wheat Deal" ran only to 10 million metric tons. Clearly, to pursue national policies in agriculture, domestic and worldwide, we need timely and accurate information that does not exist today. Space systems can assist in providing it. The Panel believes that space systems, integrated with ground information, can provide the necessary information by 1990.

ENERGY SOURCES AND DISTRIBUTION

The exploration, development, distribution, and consumption of energy resources clearly are now global problems. A recent report on the subject says:

> "The world-wide nature of energy has now intruded upon our daily lives. Whatever courses of action the United States ultimately takes to deal with energy-related problems, the ramifications of world energy realities -- the producers' cartel, the Arab-Israeli conflict, the monetary system, the global environment -- must be taken into account if they are to be realistic. The problems will not be solved in isolation or by groups of nations confronting each other. Accommodations must be reached that protect the legitimate interests of buyers and sellers, rich and poor. This will require international discussions in which all can participate.
>
> "The most immediate and real problems for most people in this world are the shortages of fuel, fertilizers and food in Africa, South Asia and parts of Latin America. Imaginative and generous forms of multilateral assistance to these people from the industrial nations and oil exporters are needed."*

The extent of domestic energy supplies, the extent of energy consumption, the dependence upon energy imports, the interdependence of energy issues with world monetary flows, and conflicting political interests and goals are issues that will stay with us for the rest of this century.

In looking at the contributions that space derived information may make to solving energy problems, to improved production or distribution, or to environmental monitoring, the Panel does not expect space systems to play a

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**Exploring Energy Choices*. Preliminary Report of the Energy Policy Project of the Ford Foundation, Ballinger Press, 1974, p. 20.

dominant role in the near term. It is in the exploration, development and exploitation of energy resources, land based and offshore, that the Panel believes space systems can make significant contributions.

The Panel has limited its considerations to space-based systems and their potential contributions to energy problems. The potential transfer of space technology ("spin-off") to ground-based applications, such as solar heating and cooling processes, the transfer of hydrogen technology, the application of teleoperator technology in land and offshore mining operations, are all possibilities worthy of examination. Yet, they are not strictly space-based applications programs.

In this restricted sense, then, the Panel considers that space systems have very important near-term potentials as a part of large system providing for energy needs as follows:

> Operations of offshore oil rigs: With the likely expansion of the use of ocean resources in the 1975-2000 period, the prediction of sea-state, weather and wind conditions for operations of oil production in offshore systems is a major, direct economic potential. In regions of adverse sea-state, such as the North Sea, offshore Alaska and the Canadian Arctic, considerable operational hazards and costs are incurred. During the winter months of 1973 alone, insurance reimbursements for damages in the North Sea oil rig operations were $35 million. Offshore field operations are all impeded by certain levels of severity of ocean weather conditions. Production is the most critical phase of the operations and is, therefore, the most susceptible to environmental conditions and improvements in predictions of these conditions. Substantial economic benefits can be expected from space applications programs. Based on experience in the North Sea and a careful extension of location of these results to about 400 offshore drilling rigs operating worldwide in 1974, new space systems presently considered by NASA for development can yield benefits of between $100 million to $300 million, by improvement over present (including present space-based) sensing systems.
>
> Routing and scheduling of oil tankers and liquified natural gas (LNG) ships: Specific systems studies need to be undertaken to analyze the potential contributions of space-based sensing and communications systems to the routing of large scale tanker operations. Specific cases involve the Alaska to West Coast oil transportation problem, Middle East to East Coast oil and LNG tanker routing and scheduling, and possibly, Arctic tanker operations. Methodology is available for such case studies. An example is included as Appendix B.
>
> Siting and monitoring of land-based and offshore nuclear plants: It is believed that a variety of present and future space-based sensors could contribute to environmentally acceptable operation of larger scale offshore structures, with adequate warning of possible adverse conditions.

United States and worldwide monitoring of oil spills and prediction of adverse sea states for avoidance of oil spills: As oil tankers have increased in size, oil spills have increased in seriousness, both in terms of the costs of damage to shores and to marine life and in terms of the cost of containing the spills and recovering the oil. The potential for accidental oil spills and illegal discharges is very high.*

Many, if not most, of the major spills are the result of accidents caused by inadequate sea-state, routing, or navigation information. For example, an Alaska to West Coast transportation case study shows that the probability of tanker collisions in large scale operations expected in the period 1985-1995 is very high, assuming presently available sea-state and routing information. Currently, information is almost invariably quite old by the time it reaches a ship. Improvements in providing real time information could be provided by using space systems. An investigation into the likely contributions of SEASAT, SMS (Synchronous Meteorological Satellite), and other new systems is considered well warranted, in view of the projected probabilities of spills and their seriousness.

In the longer term (beyond 1990), the Panel believes that space technology can make major active (production) contributions to providing energy. Solar energy is considered to be the "second" unlimited source (fusion being the "first").

MINERAL RESOURCES OTHER THAN FUELS

An adequate supply of mineral resources in the years 1980, 1990, or 2000 is one of the nation's major concerns,** and the Panel believes that the normal interplay between the factors of price, supply and demand, technical innovation and substitution, as well as reuse of minerals, will work fairly well -- but in an unpredictable way -- to meet most scarcities.

The Panel feels that space-based sensing, information, and communication systems can make very specific economic contributions to the search for and the recovery of minerals, today and in the near term. Air-borne side-looking radar systems are already in limited use for mineral exploration and the Panel believes that space-borne equivalent systems could be more cost effective. The potential benefits from the use of space systems can be defined and measured in a very specific context. A methodology on how this can be done is presented as Appendix B.

Space-based systems can help in land-based and in offshore mining operations. Some space systems can help in the exploration and development phase of mining ventures. As long as present space capabilities, such as today's communications satellites, are beneficial in these efforts, they should not be included in the benefits of additional new space capabilities. Specific potential space

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*See, for example, D. E. Kash et al, *Energy Under the Ocean: A Technology Assessment*. University of Oklahoma Press, Norman, 1973.

**See, for example, *Materials Needs and the Environment Today and Tomorrow*, Final Report of the National Commission on Materials Policy. Submitted to the President and the Congress of the United States, June 1973.

contributions identified by the Panel on Extractable Resources* should be studied in an overall systems context with an analysis of very specific applications.

COMMUNICATIONS AND NAVIGATION

From the early inceptions of the potential of space communications, through the applied research and technology phase and the prototype demonstration phase, the national development effort has been so successful that this part of space applications (common-carrier-type communications using advanced technology, as typified by Intelsat IV) has been turned over to industry.

In the Panel's opinion, the "domestic open skies" policy for communications was a further, inspired, and economically stimulating step toward a free market concept of space applications, subject only to the laws of price, demand, and supply, with long lasting beneficial economic consequences to the United States.

Nevertheless, we have to ask: given the economic success of this part of the space communications program, are there other major new opportunities in space communications and navigation that need economic, technical analysis, and development effort? In answer, the Panel feels that new economic opportunities indeed exist in all three phases of the innovative process: research and development, transitional, and operational phases.

The Panel has therefore compiled the following few comments that led it to the conclusion that there are further opportunities to be vigorously pursued by the federal government and industry.

An integrated analysis of U.S. space communications needs and opportunities is required with an outlook toward the 1985-1990 period. By integrated we mean a comprehensive assessment of federally funded efforts during R&D, transitional, and operational phases (e.g., Department of Defense and other such federal users) and of industry-funded efforts. A clear lead role should be assigned, nationally, for each of the three phases. If that lead role is not assigned to NASA (which has as a characteristic a motivation to see its R&D results applied to civil use), the transfer of the R&D and transitional phase results to civilian uses should be institutionally assured by some other mechanism in the national economic interest.

The issue of the role of the federal government as compared with that of private industry needs a constructive resolution. Civilian space-communications operations can be institutionally funded and carried out by private industry. But there are strong economic arguments for federally funded R&D efforts. The most difficult issue to be resolved is the transitional phase of *new* technology and systems.

In looking ahead to the 1985-1990 period, the Panel anticipates a substantial further increase in the demand for telecommunications and for new forms of communication. On the basis of best available projections to the 1985-1990 period, we expect about a 2.5-fold increase in the amount of telecommunications alone (household and business). This increase is projected with only simple

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*Panel on Extractable Resources. *Practical Applications of Space Systems, Supporting Paper 6: Report of the Panel on Extractable Resources.* Report to the Space Applications Board, National Research Council. National Academy of Sciences, Washington, D.C., 1975.

extensions of present ground and space-based technology, and at about present price levels. The technical capability for meeting that projected demand with present technology (Intelsat IV or V type) and expendable space transportation capabilities is seriously questioned. Rather, we would expect in this baseline projection a substantial increase (by a factor of 2) in telecommunications prices in the 1985-1990 period due to developing limitations of supply.

Therefore, we recommend that a broad "top-down" reassessment of new space communications systems for the 1985-1990 period, beyond simple extensions of present technology, be studied. Very specific R&D and transitional phase issues that evolve should be geared toward the most economical, integrated use of such new capability. A concerted effort on this particular aspect is recommended above and beyond the considerations under the first comment.

To give perspective to the magnitude of economic factors in communications in the next decade, we project total capital investment needs in all the telecommunications sectors to rise from the 1973 estimate of $70 billion to about $150 billion by 1985 (present extensions of technology). The labor force employed will stay fairly constant.

The major quantitative economic findings concerning the U.S. communications sector and in support of federal (not necessarily NASA) R&D and transitional phase funding are:

> The time lag between successful R&D activities and implementation in operational systems is anywhere between 7 to 15 years.
>
> R&D is the major factor accounting for increases in telecommunications output in the 1945-1970 period. The "rate of return" to communications R&D is about twice that of direct capital investment after allowing for a 10-percent discount rate adjustment to R&D returns (7 to 15 years).
>
> Most of the R&D and substantial portions of the transitional phase effort in the 1945-1970 period were funded by the federal government. To discontinue this history of proven applications success would set a dangerous precedent. The Panel believes that if the United States is to maintain leadership, we have to continue to push ahead in R&D, including the introduction of major new innovations in space communications systems. The benefits and the costs of alternative approaches need analysis.

PRELIMINARY DESIGN OF COST-BENEFIT STUDIES

In Appendices A and B of this report, two example cost-benefit study approaches are presented as illustrations for application of the cost-benefit techniques described earlier in this report. The Panel has not had an opportunity to review the assumptions and data in these studies in detail and as a group neither endorses nor rejects the specific findings presented. We do believe, however, that they illustrate useful approaches and suggest some important potential pay-offs from space applications.

Appendix A is a sketch of a theoretical model concerned with a weekly worldwide agricultural resources survey based on use of a space system. This study, because it is prepared while the space system is in the R&D stage, deals necessarily in broad terms both as to potential cost and benefits. It does, however, as discussed in this report, develop the assumptions made and documents them through the stages of application from R&D through operation, illustrating a methodology to be used in planning the economic scope of applications programs.

Appendix B is a case study prepared in 1974 to illustrate satellite effects on maritime traffic. In this instance, the study is concerned more with the operational phase, as both the technology and market application are fully definable for cost-benefit analysis. The results are specific and indicate marginal benefits exceeding marginal costs.

These two cases, at opposite ends of the applications cost-benefit spectrum, were chosen to demonstrate those extremes. This, it was felt, would demonstrate the potential of cost-benefit modeling for investment decision in the space applications area.

CONCLUDING REMARKS

In the course of the 1974 Summer Study on Space Applications, the Panel on Costs and Benefits has become increasingly stimulated by the potential benefits which have been identified by the user panels. At the same time, it is recognized that these benefits can only be obtained at high cost and many years in the future so that specific benefits are not fully definable now.

Future costs are almost as difficult to estimate as future benefits. If the current space shuttle payload model* is realized in the 1980-1991 era, the cumulative costs of the space applications portion of the payload model could amount by 1991 to about $11 billion in 1972 dollars for payloads, launch operations and data acquisition. The payload model projects 60 shuttle flights per year for all uses, of which about 20 flights are for applications missions. A significant number of the latter are projected to satisfy private users who might be expected to pay for the service, having independently judged the benefits to exceed the costs.

Utilization costs such as data and information processing are in addition to the above costs and, in some cases, may be much larger than the direct space-related cost. Clearly the size of the resource commitment involved dictates that only a small part of this investment should be made merely because further technical development in space is possible. Full justification must be based on a national conviction that the potential returns from space warrant the size of the investment needed to push the frontiers of knowledge further.

The complexity of the problem and the time and cost required to complete an objective analysis tempts many to abandon analysis. The alternative is to construct an appeal for funding on intuitive grounds. This is a high-risk course over the long and even the short term since it leaves the technologists and users subject to equally intuitive, even emotional, counter arguments.

The Panel on Costs and Benefits was unanimous in its conclusion that a rigorous investment and cost-benefit analysis is not only possible but would be beneficial in determining whether funds should be committed to fully operational systems. In earlier stages, investment analysis must, of necessity, be more qualitative and judgmental.

**Space Shuttle Payloads: Hearings on Space Missions, Payloads, and Traffic for the Shuttle Era.* U.S. Senate Committee on Aeronautical and Space Sciences, October 30, 1973.

The Panel has found that previous economic and cost-benefit studies of space applications have, in general, been well done. Conventional techniques have been employed which have been bounded by inputs and assumptions. Such studies have usually been aimed at quite specific, often narrow, targets. There is now a need for an integrated study approach to applications which naturally fit together in terms of joint hardware or joint uses.

The space applications program is now at the point of maturity where more conventional investment techniques, such as return-on-investment analysis, can be employed but these techniques must be applied judiciously. Most benefits and costs can be sufficiently quantified for such analysis, but many cannot.

There should be clear statements of objectives and alternative solutions. *A priori* agreements with decision-makers, such as the Office of Management and Budget, should be reached as to decision criteria.

The key investment decision points occur before the initiation of each of three phases (research and development, transitional, and operational). Each succeeding phase involves increased cost, greater commitment and, concomitantly, more concrete information on which to rationalize the pre-phase investment decision. Investment analysis should be, in fact, an on-going process during which estimates of cost and return are continuously refined.

Investment analysis should include the following factors stated to the degree of accuracy appropriate to the phase under consideration:

Economic and market research

Cost and benefit analysis

Technical confidence factors

Management and institutional definition

Break-even and return-on-investment analysis

However, studies and analyses do not, in and of themselves, make decisions but provide logic and information for human decisions.

A pricing policy for the space shuttle, for expendable vehicle alternatives, and for application services is needed as soon as possible. The shuttle with its flexible payload alternatives and capacity offers opportunities for cost savings by standardization of spacecraft and modules within and across programs, and opportunities to trade-off hardware and transportation costs.

Cost minimization should be emphasized by design-to-cost programs and clear definition of program requirements during conceptual phases.

Definition and quantification of benefits are probably the most difficult to accomplish but are amenable to modern management techniques applied on a phased basis.

Complete benefit analysis should include:

Economic analysis

Market research

Identification of end-use problems -- qualitative approach to "solutions" and quantitative benefits

Categories of benefits should be separately identified as:

Private pecuniary benefits

Social quantifiable benefits

Social nonquantifiable benefits

Public policy nonquantifiable benefits

The accumulation of data is not itself a benefit but can become a benefit when it results in some action.

Goals and missions should be clearly established for all major organizational sub-divisions, with associated management responsibilities clearly established throughout each phase and full program life.

Relationships between NASA and users should be established for:

Cost-benefit determination

Application planning

Operational program implementation

Who pays for what

The Panel on Costs and Benefits recommends that general management responsibility be specifically assigned throughout all phases of an applications program. This includes coordinating users and user working groups. In the Panel's opinion, NASA should have this responsibility in the early program phases.

To carry out even its currently assigned responsibilities, NASA has a need for in-house capability -- which it does not now have -- in requirements analysis, market research, and socioeconomic analysis.

The Panel on Costs and Benefits proposes the following as candidates for further in-depth cost-benefit studies for space applications:

Food supply and distribution

Energy sources and distribution

Mineral resources

Communications and navigation

These categories were chosen because they will present major national and worldwide problems in the next decade, and their solutions are expected to provide numerous benefits. Space applications can make an important contribution to these solutions.

The Panel on Costs and Benefits has proposed examples for the cost-benefit case models of space applications as applied to agriculture (worldwide agricultural survey) and to maritime traffic (oil-tanker routing).

This is done to make two important points:

1. Cost and benefit studies can be done with meaningful results for decision-makers, at any stage of the life cycle of a new technology (R&D, transitional and operational phases) and

2. The approach to measure the benefits of such programs is often significantly different from project to project and for each phase, requiring judgment and broad economic expertise in the many tools available for economic and investment analysis.

APPENDIX A*

CASE STUDY OF AGRICULTURE (WORLDWIDE AGRICULTURAL SURVEY)

Background

The Panel on Agriculture, Forest, and Range of the 1974 summer study has identified the desirability of weekly worldwide agricultural crop information.

In this case study, ad hoc "top-down" estimates of the potential benefits and maximum allowable research and development, transitional, and operating costs** for a 1990 Worldwide Agricultural (space) Survey (WAS) are developed. This exercise is illustrative and is not presented as a "hard" set of estimates. In particular, no attempt is made to undertake a detailed examination of the institutional and behavioral changes required to realize the potential benefits suggested. The point in presenting this example is that for cases where such large potential gains exist, further detailed investigation is clearly called for. If the kind of information system envisioned looks feasible in the cost ranges suggested herein and if the benefits suggested seem possible of at least partial realization as more definitive analysis is undertaken, then this application seems to be a strong candidate for support. We also think that an integrated view of each application is needed (multiple systems, multiple users) and that a clear focal orientation is needed for purposes of economic as well as technical analysis.

This appendix presents an uninhibited view of the need for, and potential of, worldwide agricultural information. It is a generalized economic outlook without the hard, detailed study of economic benefits and costs of actually implementing such a system. Needs were identified by the Panel on Agriculture, Forest, and Range for week-by-week worldwide agricultural information on crop acreage, condition, and calendars (plowing, planting, growing and harvesting). Clearly this is an ultimate goal for information, and not all of this information is gathered

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*This appendix utilizes information from a NASA-funded study performed by ECON, Inc., under Contract NASw 2558 and entitled *The Economic Value of Remote Sensing of Earth Resources from Space Intensive Use of Living Resources: Agricultural Distribution Effects.* ECON Report 74-2002-10, Volume 3, Part 2, Princeton, N.J., August 31, 1974.

**The term "maximum allowable costs" is used here to indicate the *upper limit* of fund allocations, i.e., within the range justifiable by expected benefits. The term does not mean that these funds have to be spent. Within the range of "maximum allowable costs" the most effective integrated system has to be found to achieve the expected benefits from the (postulated) capability.

only from space. Yet worldwide, week-by-week coverage cannot but rely heavily on space sensing systems (ERTS, EOS, SEOS, NIMBUS, SMS, SEASAT, and communications satellites).

Several points that deserve emphasis follow:

Such a worldwide system design is a long-term goal.

Such a system is very ambitious and relatively costly when compared to present space applications efforts.

The determination of benefits to the United States and to all nations needs careful study.

The degree to which the benefits from such information can be realized will heavily depend on how this information is processed and made available to some or all users and whether users act on the information in the directions assumed here.

Two larger questions need to be addressed now:

Do the overall potential benefits far outweigh any likely, rationally managed systems costs (R&D prototype, development, and operations) of a long-term program commitment by the United States?

If the answer to this first question is yes, can such a long-term commitment be a purpose and goal of the U.S. space effort, and can it be undertaken in terms of the investment needed to do so and in terms of benefits to the nation and mankind?

The Current (July 1974) World Food Grain Situation

As the peak growing season of 1974 approaches, events lead one to believe this is a year in which the outcome of the spring food grain harvest will be extremely important to the economic and political stability of the world. Grain stocks have not been rebuilt since 1972 when large reductions resulted from poor crops in many areas of the world. This year (1974), as a result of inclement weather, the spring crops were planted very late in North America and in the western areas of the USSR. Moreover, the Indian monsoon is now two weeks late and the possibility of a monsoon failure must be considered seriously. Out of a potential world food grain crop of 710 million metric tons (MMT), at least 100 MMT are growing under high risk conditions. With stocks at a minimum, the allowable margin for error is obviously small. Poor weather in any one of several key grain-producing areas could result in a world food crisis of a magnitude that is beyond our current ability to rationalize. Needless to say, it is important that those supplies that are produced be distributed efficiently. Accurate and timely information about prospective crop conditions is vital to the distribution process today. Over the next decades, this precarious balance seems likely to increase in importance.

The following paragraphs describe briefly the current situation as it exists in several key areas and indicate the major threats to the crops in those areas.

> The spring wheat crop in North America is a fast growing variety which matures in 95 to 100 days. It is normally planted by late May and harvested by the end of August. This year well over half of the spring wheat crop was not planted until early June (this was the latest planting in history) and will not mature until mid-September. The threat of frost damage is very real and an early frost could be disastrous. The producing area is bounded by 112°W and 95°W and 45°N and 55°N.
>
> The spring wheat crop in the USSR was planted late also, but no one knows exactly how late. This wheat is grown in a semi-arid climate in the central portion of the USSR and is a risky crop in any year. This year it is threatened by drought, as usual, but, because of the late planting, harvesting condition may be a problem also. Strangely enough, the harvest in this part of the USSR is just before a rainy season. The coordinates are 65°E and 90°E and 45°N and 57°N.
>
> The outcome of the Indian monsoon, while critical, will be well known in the next few weeks.
>
> Chinese weather information is difficult to obtain, but there is evidence of drought in the Peking area. Most food grain is produced in the area bounded by 110°E and 120°E and 40°N and 52°N.

Likely Impact of Information Uncertainty

Extensive economic research is presently ongoing in determining the value of information in U.S. agriculture. One significant ingredient in this determination is the reaction of food grain prices to changes in expected food crops. Any best estimate to date (July, 1974) of this relation between food prices and food quantities is an "elasticity of demand" of about 0.15 for wheat (interim estimate), and somewhat lower for total food grains; i.e., a 1-percent rise in wheat prices will lead to a 0.15-percent reduction in wheat consumption and conversely, a 1-percent reduction in the expected quantity of wheat crops will lead to a 6- to 7-percent increase in the price for wheat food crops.

This key finding, when applied to the current world food situation, and existing uncertainties therein, leads to the following observations:

> The distribution value of the 610 MMT not growing under high risk conditions will be about $196 billion, with a needed extreme readjustment of inventory, consumption, export, and import decisions. The value of 100 MMT growing under high risk would be about $24 billion. Many independent decisions and decision-makers are involved. At these prices, crops presently not harvested or plowed under for the next crop cycle might be

harvested, and land not now cultivated might be opened, or land now only used "extensively" might be irrigated, fertilized, etc. Yet we will not know for another 8-12 weeks what the actual conditions of worldwide food crops will be, although these could be determined, to a major extent, by WAS systems.

Case 1 (Maximal Benefit)

The market immediately expects the worst, i.e., that instead of 710 MMT, only 610 MMT will be harvested. Prices now prevailing (about $161 per metric ton of food grain) will rise according to the measured elasticity of 0.15 to a level around $322 per metric ton. (See Figure I.) The U.S. grain export volume of $18 billion will rise to a level of $36 billion at the end of the crop exporting period with an average export revenue flow of $27 billion (a heavy cost this year to consumers).

If it turns out that, contrary to expectations, all four critical regions perform adequately, i.e., the marginal 100 MMT are harvested and next year's production will continue at 710 MMT (steady state), then next year there will be 810 MMT (710 MMT harvested, plus the 100 MMT of 1974 "windfall" harvests) available for distribution. Prices will then drop to about $80 to $100 per metric ton. United States exports will drop from a steady state volume of $18 billion (initially) to about $10 billion (after 12 months), with an average annual volume of about $14 billion; this adjustment leads to a benefit next year (1975) to consumers, albeit smaller than this year's cost. (See Figure I.) The total social net loss due to this present lack of information about what might happen two months hence is about $8 billion worldwide, the total U.S. domestic loss is about $2 billion (about 1/4 of the $8 billion), and losses due to U.S. export decision uncertainties about $3.2 billion.* Total U.S. losses could be as high as $5.2 billion. The timely use of WAS information is a necessary condition if these losses are to be avoided.

Case 2 (Likely Gains)

The originally expected world food grain crop for 1974 was 710 MMT. The total uncertainty in the expected harvest, however, was about 100 MMT (see Case 1).

The remote sensing systems now being considered will not eliminate all of this uncertainty, even with a considerable investment in new technology, and even after 10 to 15 years of operational systems use. A considered judgment -- for purposes of this exposition -- is that a 25-percent reduction in the total uncertainty is reasonable by 1990 -- for worldwide food crop harvest measurements, i.e., a reduction from 100 MMT to 75 MMT.

This 25-percent reduction in uncertainty is depicted in Figure II, with the economic gains from this reduction indicated by the hatched area. The reader will

*All quantitative estimates given here are based on analyses of the U.S. agriculture sector, applied worldwide.

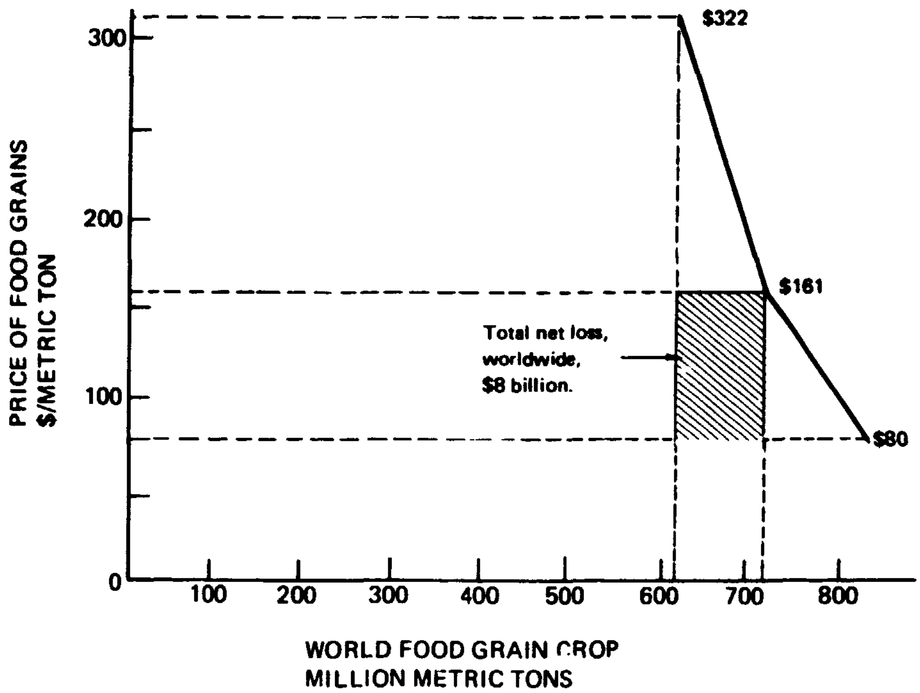

FIGURE I CASE 1 - MAXIMAL BENEFIT

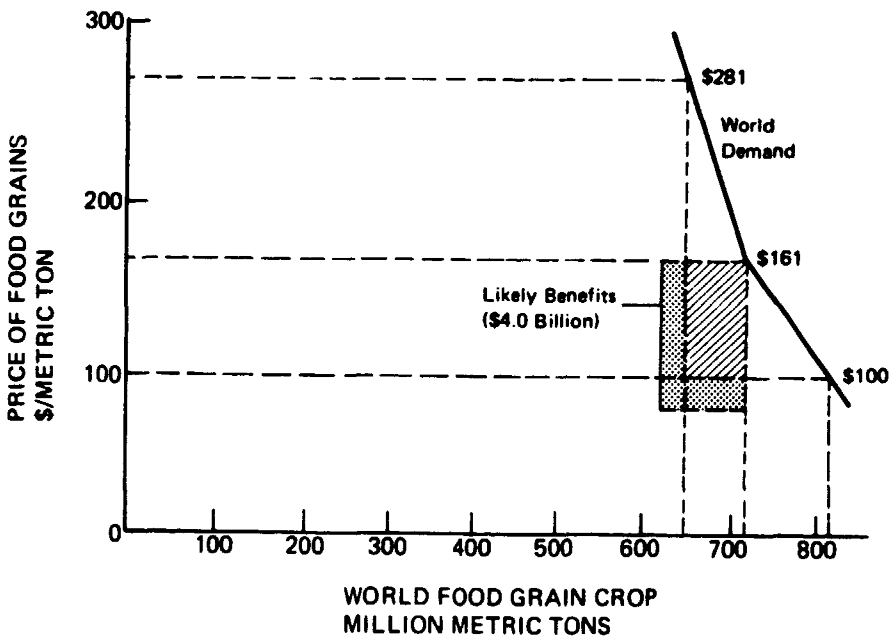

FIGURE II CASE 2 - LIKELY GAINS

notice that a 25-percent reduction in uncertainty leads to about 50-percent of the total benefits attributable to perfect information. The improvements to be brought about by remote sensing technology in the next 10 to 15 years will make the most important potential contribution, while improvements beyond the assumed 1990 level of crop information technology will be less beneficial. There are decreasing economic returns to further incremental improvements.

Figure II depicts -- with price elasticity as of June, 1974 -- the likely reactions of world food grain markets and the total expected net loss to society as a result of this reduction in uncertainty. The total net worldwide gain from this improvement is about $4 billion of which $1 billion is the total net domestic United States gain. United States export decisions would now range between $12 billion, with likely U.S. gains from this reduction in uncertainty of $1.6 billion. Total potential U.S. gains due to this reduction in uncertainty are about $2.6 billion ($1 billion U.S. domestic gains, $1.6 billion gains from improved export decisions).

Again, all of these numbers are initial estimates. Firmer estimates for cases in R&D policy decisions will require considerable empirical work -- in some areas even advances in the state-of-the-art in economics. But such measurements are indeed possible.

Extension to WAS Information Benefits

Cases 1 and 2 describe the situation of July 1, 1974, about 2 months before final Northern Hemisphere crop harvests. Uncertainties, in fact, exist throughout the crop year, in both the Northern and Southern Hemispheres. With food grain inventories depleted, the uncertainties throughout the crop year are probably best described by Case 1 results. All of WAS information (by remote sensing such as ERTS, EOS, SEOS, NIMBUS, SMS, SEASAT) on a weekly basis throughout the world, taking cloud cover into account (for cloud cover-sensitive systems like ERTS), may lead to only a 50 percent reduction in existing uncertainties. Therefore, the total quantitative loss estimates of Case 2 (2 months) also represent likely minimum gains from WAS. Added to this estimate should be expected gains in production (we estimate about 1/4 of the distribution benefits) of about $800 million, for a total net value added assessment of WAS as shown in Table I.

	United States	World
Distribution	$1.0 billion	$4.0 billion
Export/Import	1.6 billion	large
Production	.8 billion	3.2 billion
	$3.4 billion	$7.2 billion plus

TABLE I POSSIBLE ANNUAL GAINS FROM WAS OVER PRESENT INFORMATION STATE

Implications of Results to Space Applications Program

Considering U.S. benefits only of Table I, the 1974 present value of an operational WAS program from 1990 onward (infinite horizon)* at 10 percent discount, is $8.4 billion total. (The 1990 value of $3.4 billion annually from thence forth is approximately $34 billion which discounts to $8.4 billion in 1974.) To realize these benefits, and provide for basic costs, cost uncertainties and overruns, a research, development, demonstration, and implementation program as shown in Table II would be "allowable."

	1975-79 R&D	1980-84 R&D	1985-90 Transitional	1990 on Operational
Annual budget	$200 million	$400 million	$800 million	$200 million per year
Total budget for years indicated	$1 billion	$2 billion	$4 billion	

TABLE II MAXIMUM ALLOWABLE WAS R&D, TRANSITIONAL AND OPERATIONAL PHASE COSTS

The present value of the WAS R&D, transitional and operational phase investment cost (again with infinite horizon from 1990 onward) is $4.2 billion at 10 percent discount. Figure III shows the total "allowable" WAS program life cycle costs and benefits (U.S. only). The WAS investment, seen in this context, would return, after allowing for a 10 percent discount rate, $2 for every $1 spent, based on benefits to the United States only, and much more if WAS can be developed for a lower cost.

Major Tasks for In-Depth Analysis

There exist overlapping user needs and space system requirements between the Agriculture, Forest, and Range, Land Use, Extractable Resources, Weather and Climate, and Environmental Quality Panels of the 1974 Space Applications Study. An integrated investment study of agricultural earth resources surveying programs from space is clearly called for. The term "integrated investment study" is meant to include the use of all available, and potentially conceivable, remote sensing systems from space, analyzed toward achieving one common overall

*An infinite horizon for evaluation purposes of WAS is clearly indicated for a national decision, although this may not be intuitively obvious.

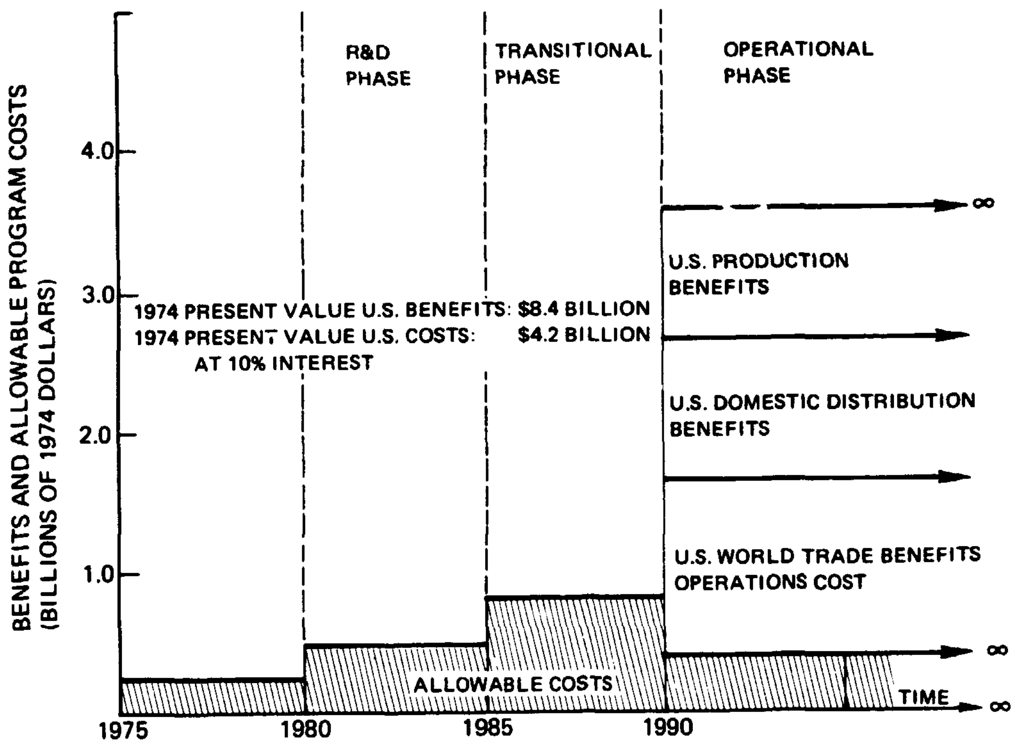

FIGURE III TOTAL WAS PROGRAM LAYOUT

goal, for example, a 1990 operational worldwide weekly agricultural survey capability. The components of such a total investment analysis are:

Measurement of Likely Benefits of an Operational Integrated System: All available tools of economic analysis, such as market research approaches as well as economic analysis and estimation techniques, have to be brought to bear on this part of the problem, requiring experience, imagination, and improvisation, where necessary. New econometric models of the agricultural sector do not yet exist and have to be developed, tested, and estimated. These models must specifically be suited for measuring the value of more timely and more accurate information derived from remote sensing. This is a research effort of some magnitude.

Production effects, distribution effects, and world trade effects each need separate analysis. Also, as the integrated systems definition progresses, the detail of economic analysis can expand and aid in the technical systems definition and trade-off studies.

Determination of "Maximum Allowable" Research, Development, Investment and Operations Costs of An Integrated System: The part of the analysis concerned with maximum allowable costs translates the expected future benefits of an operational system into upper boundaries to the total national program budgets needed to bring about an operational WAS system. It is within these budget constraints that the total integrated system has to be designed, developed, deployed and operated. (See Figure III.)

Determination of Most Economical (Effective) Integrated Systems Within Imposed Budget Constraints: The satellites ERTS, EOS, SEOS, NIMBUS, SMS, to mention a few, all have to be examined, system by system and later subsystem by subsystem, as to their relative contribution and merit to the overall program goals within the imposed budget limits. Again, many tools of economic-investment and operations-research analysis exist to do this demanding part of the analysis.

Requirements: In any one of the above three parts of an integrated agricultural earth resources survey analysis, close cooperation with the Office of Management and Budget (OMB) is desired, particularly in the initial program study phases. Ground rules should be agreed upon, techniques reviewed, and where necessary, the OMB as well as the federal agencies involved should be open to a redefinition of the approach and the ground rules.

Important institutional questions need study and resolution in parallel with the technical and economic analysis of this application potential.

Review of WAS Benefits

The July 1, 1974, worldwide agricultural food grain crop situation is taken as the baseline for the estimates. Of an originally expected 710 MMT world food grain crop, about 100 MMT are now growing in high risk areas: North America (112°W to 95°W and 45°N to 55°N), USSR (65°E to 90°E and 45°N to 57°N), China (110°E to 120°E and 40°N to 52°N) and the Indian Subcontinent. With a 700 MMT world crop, we estimate 1 MMT to be worth \$160 million; with a 600 MMT world crop, we estimate 1 MMT to be worth about \$300 million. Gains from a 1990 WAS system are estimated in Table I.

The rationale for production benefits is the interaction between more accurate, early price information with acreage allotment, plowing, growing and harvesting decisions. (No institutional innovation is assumed here.) The rationale for import-export benefits is a combination of distribution production benefits in international trade.

The present value in 1974 of these annual benefits to the U.S. from 1990 to an infinite horizon is, at a 10 percent discount rate, $8.4 billion. These benefits will be realized only by drawing on a whole range of space systems -- rather than any one single spacecraft system -- such as ERTS, EOS, SEOS, SMS, and NIMBUS.

In relating the benefits to the R&D, transitional, and operational phase costs, the term "maximum allowable" costs is used. This term denotes the upper limit of expenditure levels based on the estimated benefits. These figures are not an estimate of costs.

A maximum allowable R&D, transitional and operational phase budget is developed, with allowable R&D phase costs of $200 million per year from 1975 to 1979, $400 million a year from 1980 to 1984, maximum allowable transitional phase costs of $800 million a year from 1985 to 1989, and systems operational cos of $200 million a year from 1990 to infinity. The present value of these maximum allowable costs is $4.2 billion.

On every $1 invested, $2 would be returned after discounting benefits and costs at 10 percent. The benefits include U.S. benefits only.

An in-depth systems and economic study of such a program is recommended. WAS would consist of an integrated use of systems like ERTS, EOS, SEOS, NIMBUS, SMS and would use the Tracking and Data Relay Satellite for real time communications.

The allowable R&D and transitional costs can be considered maximum allowable budget limits to U.S. space applications activities for broad agricultural uses.

Further study should include:

Investigation of the private gains (above social gains not included here) to be accrued through the exclusive use of WAS information.

Analysis, similar to that used for U.S. benefits, of the effects of improved information on world trade. Two cases should be analyzed: (1) WAS information made available to all countries, (2) WAS information available only to the United States.

Definition of the ranges of social and private gains, which vary substantially, depending on how and to whom WAS information is made available.

All of the identified areas and sources of social and private gain need empirical work; i.e., the facts have to be checked and verified through quantitative, econometric work over 12 to 24 months, in parallel with an integrated systems engineering study of user technical needs.

APPENDIX B

USE OF SATELLITE DATA ON THE ALASKAN OIL MARINE LINK*

I. Introduction

Oil must be carried by tanker from one port of origin at Valdez, Alaska, to three ports of destination on the west coast of the United States (since the final designation of ports has yet to be made, they were assumed for this study to be the ports of Juan de Fuca at Seattle; Coos Bay, Oregon; and Santa Barbara, California) to complete the link between the Northern Slopes field and the U.S. consumers. There will initially be 13 tankers dedicated to delivering this oil. Oil will flow into Valdez from the Northern Slopes of Alaska at the rate of 1,200,000 barrels per day. Both the number of tankers (13) and the production of oil in Valdez (1,2000,000 barrels per day) will be increased in subsequent phases.

There will be storage capacity to serve as buffers in the production and distribution process. The storage tanks will be located at Valdez as well as at the three west coast ports. This marine link is illustrated in Figure I.

Using more timely satellite forecasts may impact on the operation of this link in several ways. An accurate weather and

*This appendix is based on work done by William E. Steele, ECON, Inc., for the National Aeronautics and Space Administration. The appendix will appear as a paper in a future issue of *Journal of Transport Economics and Policy*.

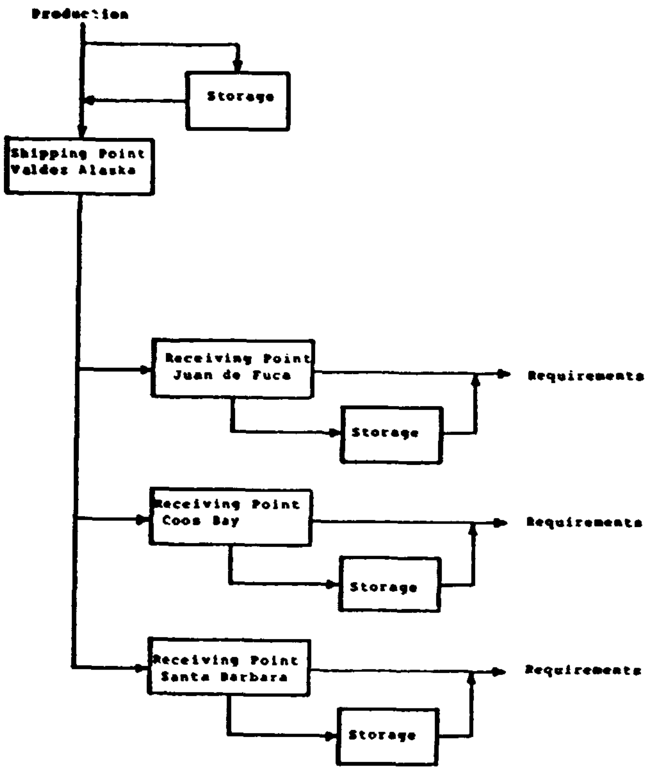

Figure I Overview of Alaskan Oil Marine Link

ocean conditions forecast may prevent a ship from leaving port and sailing into a storm. The tanker can remain in port if the storm is brief and intense or it can sail out and make an immediate diversion to avoid the storm. A ship in stormy weather must cut its speed, sometimes by as much as fifty percent. In addition to the time loss, the probability of damage, loss of life and oil spill through grounding or collision increases.

Also, when a ship is at sea, a timely and accurate weather and ocean conditions forecast may permit alternatives in routing that will enable it to by-pass the storm. This maneuver is somewhat limited on the Alaskan run. The basic route hugs the coast and adjustments can only be made by heading out to sea. There is, thus, little if any time saving by this particular action. But, of course, the weather damage of the storm is still avoided in this instance. In addition to this maneuver, if conditions are improving, the tanker may be sent on a more direct route which was initially stormy. This gains time and fuel and avoids weather damage. Thus, the benefits of routing are threefold. First, it saves time and the operating costs associated with the time saving, principally labor costs. Second, it saves fuel because the tankers spend less time at sea and maintain a more steady and efficient speed during that time. And third, it lessens weather damage.

Besides better weather and ocean conditions forecasts, the oil shipment costs will be affected by the utilization of the various type tankers to the different ports. This is because the tanker types vary in their cost of delivery per barrel and because the ports are not equidistant. It was necessary that any benefits model be able to distinguish between cost savings arising from better weather forecasts or from better utilization.

A mathematical model was developed to permit analysis of the utilization problem and to allow for the impact of better weather and ocean conditions information. By a systematic simulation procedure with the model it was possible to separate the influences of utilization from weather forecasting. The model was kept general enough to apply to any marine transport link system with one origin, multiple destinations, a dedicated fleet of ships of varying capacities, and storage capability at the origin and destinations.

II. The Model

The basic cost parameter on which the model is built is the cost of shipment per barrel. The cost of shipping a barrel of oil depends on the size of the tanker, the time of the year, and the port of destination to which it is to be shipped. This may be expressed as

$$\alpha_{ijk} = a_{ijk}\,\lambda_j$$

where

a = cost of shipping one barrel of oil (\$/barrel)

λ = the capacity of the tanker (barrels/shipload)

α = cost of a full tanker delivery (\$/shipload)

i = time period

j = tanker type

k = destination

which is the cost of shipping one shipload of oil in period i by tanker type j to destination k.

If satellite information proves beneficial, a percentage decrease in any period i in the cost of shipping a barrel of oil of the magnitude of δ_i should be expected. Multiplying both sides by $(1-\delta_i)$, we get the new cost of a full tanker delivery as

$$(1-\delta_i) \quad \alpha_{ijk}$$

Besides this cost of delivering a tanker filled with oil, the marine decision must consider the storage capacity and the associated costs at both ends of the marine link. For example, if costs of shipping are expected to be especially high in the next period due to bad ocean conditions, shipments in that period may be suspended in favor of increased shipments in the present period, increased storage at the destination in the given period and increased shipments in the subsequent run. In general, trade-off can be made amongst shipments, storage at the origin and storage at the destination and among the various size tankers. For the sake of simplicity it will be assumed that there is not significant oscillation in the storage of oil in a single time period. Storage either increases or decreases linearly in a given period. Further, it is assumed that there is a part of the operating cost of the storage operation which is linearly proportional to the amount of oil in storage. This leads to a cost minimization objective function of the form

$$C=\sum_{i=1}^{t} \sum_{j=1}^{m} \sum_{k=1}^{n} (1-\delta_i)\, \alpha_{ijk} \quad X_{ijk} + \sum_{i=1}^{t} \beta_i \left(\frac{Y_i + Y_{i-1}}{2} \right)$$

$$+ \sum_{i=1}^{t} \sum_{k=1}^{n} \gamma_{ik} \left(\frac{Z_{ik} + Z_{i-1,k}}{2} \right) \qquad (1.1)$$

where

C = total cost of marine link for period 1 to t ($/periods 1 to t)

X_{ijk} = number of shiploads in period i of tanker type j shipped to destination k (# of shiploads/period)

Y_i = number of barrels of oil in storage at the end of period i at the origin (barrels)

β_i = cost of storing one barrel over peiod i at the origin ($ per barrel/period)

γ_{ik} = cost of storing one barrel over period i at destination k ($ per barrel/period)

t = number of periods of analysis

m = number of types of tankers, classified by capacity

n = number of destinations

subject to all X, Y, and Z $\geq$ 0.

It might be noted that X, Y, and Z are not expressed in the same basic unit, i.e., a barrel. Since expressing X in barrels does not give meaningful figures, the barrel capacity per shipload, λ, was separated from the number of shiploads, X, as indicated above. The variable X is interpreted as the number of shiploads hereafter. The same procedure must be observed in the constraints when expressing barrels shipped. There are five sets of constraints to be imposed. These apply to production, requirements, shipping, storage at the origin, and storage at the destination.

The amount produced each period must either be shipped out or added to the storage of the previous period

$$\sum_{j}^{m} \sum_{k}^{n} \lambda_j X_{ijk} + (Y_i - Y_{i-1}) = P_i \quad \text{for all } i$$

or

$$\sum_{j}^{m} \sum_{k}^{n} \lambda_j X_{ijk} - Y_{i-1} + Y_i = P_i \quad \text{for all } i \qquad (1.2)$$

where

P_i = number of barrels produced in period i (barrels/ period)

The amount required at each destination each period must be obtained from what was shipped that period or by drawing down on storage.

$$\sum_{j}^{m} \lambda_j X_{ijk} + Z_{i-1,k} - Z_{ik} = R_{ik} \quad \text{for all } i \qquad (1.3)$$

where

R = number of barrels required in period i in destination k (barrels/period)

Another constraint which must be imposed is that the number of trips hich can be made by a given fleet is limited, essentially by the finite speed of the ships. Suppose the $\overline{X}_{ijk}$ is the maximum number of trips which can be made by all tankers in class j to destination k in period i, assuming that the tankers experience average delays due to weather. Further, define:

b_{jk} = the number of tankers in class j going to k each period

$\overline{d}_{ik} = \dfrac{\overline{X}_{ijk}}{b_{jk}}$ the maximum number of trips which can be made in period i by any tanker going to destination k (tankers, regardless of size, find it efficient to maintain a speed of approximately 16 knots).

$b_j = \Sigma\, b_{jk}$ the total number of ships of type j in the fleet (sum over k)

d_{ik} = the maximum number of trips which can be made by one ship to k with no weather delays in period i.

$\Theta_i = 1 - \dfrac{\bar{d}_{ik}}{d_{ik}}$ the fractional decrease in number of trips possible due to weather delays; assumed independent of destination.

Clearly, then $\dfrac{X_{ijk}}{\bar{X}_{ijk}} \leq 1.$

But $\bar{X}_{ijk} = b_{jk}\bar{d} = b_{jk}d_{ik}\ (1-\Theta_i)$, so that $\dfrac{X_{ijk}}{d_{ik}} \leq b_{jk}\ (1-\Theta_i)$.

Summing over all destinations, we find the final form of the constraint:

$$\sum_{k=1}^{n} \frac{X_{ijk}}{d_{ik}} \leq (1-\Theta_i)\ b_j \tag{1.4}$$

For the storage constraint at the origin, we have

$$Y_i \leq S_i \text{ for all } i \tag{1.5}$$

where

S_i = storage capacity at the origin in period i (barrels/period)

Initial and final yearly constraints are added to these storage constraints

$$Y_o = S_o \text{ and } Y_t = S_t$$

This will add one variable, Y_o, to the objective function.

In analogous manner, the constraints on storage at each destination are:

$$Z_{ik} \leq D_{ik} \text{ for all } i, k \tag{1.6}$$

where

D_{ik} = storage capacity in period i at destination k (barrels/period)

When the initializing constraints are imposed n variables, Z_{ik}, are added to the objective function.

Thus, the statement of the linear programming problem is complete. The objective function is (I.1) with

$$\text{\# of variables} = 1+n+t[1+n(1+m)] \text{ and}$$

five sets of constraints, (1.2), (1.3), (1.4), (1.5) and (1.6) which yield

$$\text{\# of equations} = 1+n+t(2+2n+m)$$

The number of equations is further restricted to be less than the number of variables. This means that:

$$m > \frac{n+1}{n-1}$$

$$\text{or} \quad n > \frac{m+1}{m-1}$$

And finally we must add the non-negativity constraint, i.e., all X, Y, and Z $\geq$ 0.

The full restatement of the resulting linear programming problem is presented in Tables I and II.

III. Use and Economic Interpretation of the Model

The linear programming model discussed in the previous two sections enables us to measure the decreased cost of the Alaskan oil marine link when there is improved utilization of

Table 1 Summary of Equations
Alaskan Oil Marine Link Model

$$C = \sum_{i=1}^{t} \sum_{j=1}^{m} \sum_{k=1}^{n} (1-\delta_i)\, \alpha_{ijk}\, X_{ijk} + \sum_{i=1}^{t} \frac{\beta_i}{2} (Y_i + Y_{i-1}) + \sum_{i=1}^{t} \sum_{k=1}^{m} \frac{\gamma_{ik}}{2} (Z_{ik} + Z_{i-1,k}) \tag{1.1}$$

Subject to

production constraints

$$\sum_{j=1}^{m} \sum_{k=1}^{n} \lambda_j X_{ijk} - Y_{i-1} + Y_i = P_i \text{ for all } i \tag{1.2}$$

requirements constraints

$$\sum_{j=1}^{m} \lambda_j X_{ijk} + Z_{i-1,k} - Z_{ik} = R_{ik} \text{ for all } i, k \tag{1.3}$$

shipping constraints

$$\sum_{k=1}^{m} \frac{X_{ijk}}{d_{ik}} \le (1-\theta_i)\, b_j \text{ for all } i, j \tag{1.4}$$

storage at origin constraints

$$Y_i \le S_i \text{ for all } i \tag{1.5}$$

storage at destinations constraints

$$Z_{ik} \le D_{ik} \text{ for all } i, k \tag{1.6}$$

and

X, Y, Z all ≥ 0

# of equations $\le$ # of variables.

ships and improved weather forecasting. How does this translate into benefits? How much of the decrease in cost is due to weather forecasting and how much is due to better utilization? This section answers these questions.

First, we must answer the more basic question. What is the value of the Alaskan oil initially? To answer this we look at the supply and demand curves involved. The present world supply and demand for oil without Alaska looks something

Table II Definitions for Equations in Table I

Coefficients

- i - time period (t - total number of time periods)
- j - tanker type (m - total number of tanker types)
- k - destination (n - total number of destinations)
- Δ_i - percentage decrease in cost of shipping a barrel of oil in period i (%)
- α_{ijk} - cost of a full tanker delivery in period i by tanker type j to destination k ($/shipload)
- β_i - cost of storing one barrel at the origin over time period i ($ per barrel/period)
- γ_{ik} - cost of storing one barrel at destination k over time period i ($ per barrel/period)
- λ_j - the capacity of tanker type j (barrels/shipload)
- d_{ik} - the maximum number of trips which can be made in period i by one tanker type j (# of trips)
- θ_i - the fractional decrease in number of trips possible due to weather delays in period i (%)
- b_j - the number of type j tankers in the fleet. (# of tankers)

Variables

- C - total cost of marine link for periods 1 to t ($)
- X_{ijk} - number of shiploads in period i delivered by tanker type j to destination k (# of shiploads)
- Y_i - number of barrels of oil in storage at the origin at the end of period i (barrels)
- Z_{ik} - number of barrels of oil in storage at destination k at the end of period i (barrels)
- P_i - number of barrels produced in period i (barrels)
- R_{ik} - number of barrels required at destination k in period i (barrels)
- S_i - storage capacity at the origin in period i (barrels)
- D_{ik} - storage capacity at destination k in period i (barrels)

like Figure II where S_o^w is the world supply curve and D_o^w is the world demand curve. Before the Alaskan oil is available, the world price is P_o^w and the quantity supplied is q_o^w. We are assuming that the world demand is inelastic and the world supply is more elastic as drawn. (The Hudson-Jorgenson model of oil demand estimates the elasticity of demand for oil to be -.15, while the Erikson-Spann econometric model finds the elasticity of supply for oil to be +.85. See Adelman [2, p.29 and p. 34, respectively].)

When Alaskan oil becomes available, it will be available at a significantly lower price but not in sufficient quantity to satisfy the U.S. demand. Therefore, the Alaskan oil will be fully consumed and there will be a corresponding shift downward in the world demand curve, as pictured above, to D_1^w. Since the Alaskan oil is earmarked for U.S. markets and since there will be at least implicit price control, <u>two markets will develop</u>, each with its own supply and demand and price. In the world market, exclusive of Alaskan oil, the quantity demanded will drop back by the amount of oil supplied from the Alaskan fields to $q_o^{w'}$. But at this point the available supply exceeds the world demand and there will be some downward pressure on price. This will induce the quantity demanded to increase beyond $q_o^{w'}$ and the dropping price will not draw forth the previous supply of q_o^w. The new equilibrium point will be price p_1^w and quantity q_1^w .

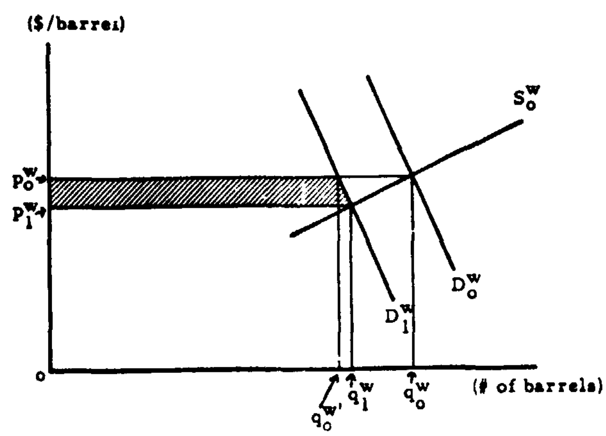

Figure II World Supply and Demand for Oil (Excluding Alaskan Oil)

The supply and demand for Alaskan oil can be illustrated as in Figure III.

Assuming q_a^1 is the maximum amount of Alaskan oil which can be brought into the U.S. market from Alaska each year (i.e., the supply curve becomes vertical at q_1^a), we would find that the demand would be insatiable, i.e., the demand curve would be horizontal as presented.

The consumers were initially consuming quantity q_o^w at price p_o^w. We know

$$q_1^a = q_o^w - q_o^{w'}$$

So, the consumers are obtaining $q_1^w - q_o^{w'}$ extra oil, $[q_o^w = q_o^{w'} + q_1^a] < [q_o^{w'} + (q_1^w - q_o^{w'}) + q_1^a]$.

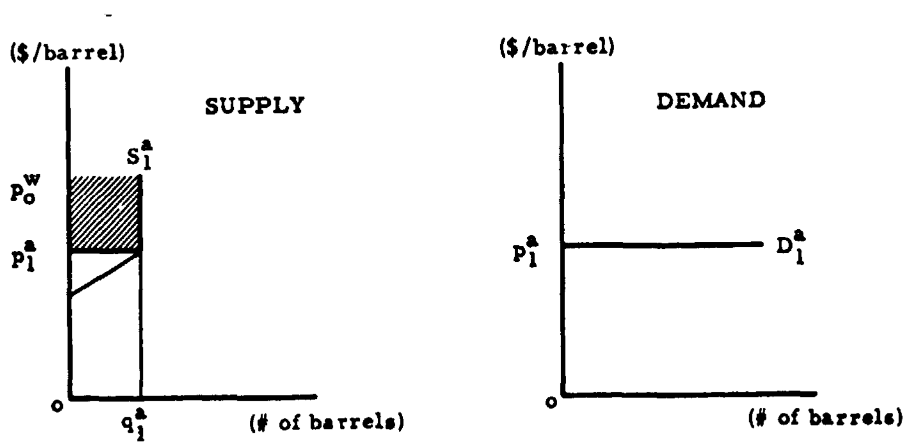

Figure III Supply and Demand for Alaskan Oil

The consumers are consuming q_1^w and q_1^a at prices p_1^w and p_1^a, respectively.

In conclusion, we see the consumers are paying lower prices and getting more oil. This benefit is represented by the sum of the shaded areas in the two diagrams above and it is the consumer's surplus.

We derive this benefit mathematically as follows:

$B_1 = q_1^a \times (p_o^w - p_1^a)$ = A direct benefit.

Assuming linear supply and demand curves and knowledge of the elasticity of supply (ε_s), elasticity of demand (ε_d), p_o^w, q_o^w, and $q_o^{w'}$ (from $q_o^{w'} = q_o^w - q_1^a$) we have two equations

$$\varepsilon_s = \frac{\dfrac{q_o^w - q_1^w}{q_o^w}}{\dfrac{p_o^w - p_1^w}{p_o^w}} \quad \text{and} \quad \varepsilon_d = \frac{\dfrac{q_o^{w'} - q_1^w}{q_o^{w'}}}{\dfrac{p_o^w - p_1^w}{p_o^w}}$$

with two unknowns, p_1^w, q_1^w. Simultaneous solution of these two equations yields the equilibrium values

$$p_1^w = p_o^w \left[1 + \frac{q_o^w - q_o^{w'}}{\varepsilon_d q_o^{w'} - \varepsilon_s q_o^w} \right]$$

$$q_1^w = \frac{q_o^w \; q_o^{w'} \; (\varepsilon_s - \varepsilon_d)}{\varepsilon_s q_o^w - \varepsilon_d q_o^{w'}}$$

We then have

$$B_2 = (p_o^w - p_1^w) \times q_o^{w'} = \text{A direct benefit}$$

and

$$B_3 = (p_o^w - p_1^w) \times (q_1^w - q_o^{w'}) \times 1/2 = \text{The induced benefit}$$

and finally

$$B = B_1 + B_2 + B_3 = \text{Total benefit of Alaskan oil} = \text{Sum of shaded area}$$

We have completed our discussion of the benefits of Alaskan oil and are now in a position to estimate the impact of weather forecasting. In general, better weather forecasting can be expected to increase B_1 directly, but it will impact on B_2 and B_3 imperceptibly. We will focus on the increase in B_1 and ignore the negligible changes in B_2 and B_3.

There are two outputs from the linear programming model which are of particular importance to us. These are the total cost, C, and the sum of the requirements met in each period i at each port k, $\sum_i \sum_k R_{ik}$. Both of these are a function of how weather forecasting impacts on the percentage change in the cost of shipping a barrel of oil, δ, and the percentage change in the number of trips a given type tanker can achieve, θ. That is

$$\Delta C = f(\delta, \theta)$$

$$\Delta \sum_{i} \sum_{k} R_{ik} = f(\delta, \theta)$$

In regard to the $\sum_{ik}\sum R_{ik}$, we should take note of the fact that the requirements met may be less than what is produced because the shipping capacity is insufficient. In this case, additional oil may be supplied to U.S. consumers by the use of satellite weather information to route the tankers around storms and high seas. When the shipping capacity is already sufficient to deliver the full production of oil, the only benefit to be realized is a decrease in the cost of supplying the oil and in the subsequent price to the consumer. We may illustrate these two exhaustive possibilities as in Figure IV.

In case a) the shipping capacity was already sufficient when weather forecasting was introduced, so the only impact is a lower price for the consumer. In case b), we see that the supply curve was at S_3^a and the quantity delivered to the consumer was q_3^a. After weather forecasting is introduced, we move to S_4^a and q_4^w and the benefits of extra

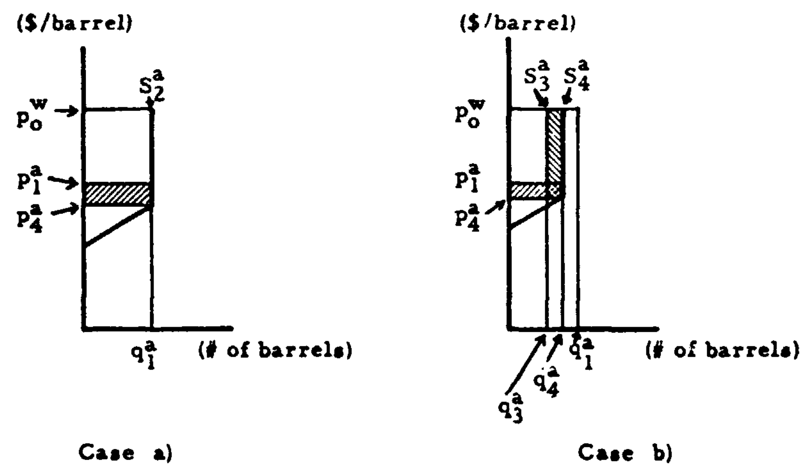

Figure IV Benefit of Satellite Information on Alaskan Oil Marine Link oil (the vertical shaded area in Figure IV, b) is added to the benefit of lower cost

In general, the benefit of satellite weather forecasting on the Alaskan marine link is then given as

$$B_1' = (P_1^a - P_4^a) \times q_k^a$$

where

$$q_k^a = \text{min of } (q_1^a, q_3^a)$$

$$B_1'' = (P_o^w - P_4^a) \times (q_4^a - q_3^a)$$

subject to

$$B_1'' = 0 \text{ if } q_4^a > q_1^a$$

Total Benefit = $\Delta B_1 = B_1' + B_1''$ (1.7)

The total benefits were calculated using equation (1.7). Since some benefits arose from better utilization of tankers, it was necessary to proceed systematically to isola the influence of the satellite. (Note: Fixed utilization refers to the utilization scheme for tankers defined by Alyeska for the Department of the Interior [6]. In this scheme, each type tanker visits each port a fixed number of times each year.)

We define the following four cost concepts:

Cost I, C (I)	- calculated assuming fixed utilization and no satellite weather forecasting. The baseline case.
Cost II, C(II)	- calculated assuming fixed utilization with satellite weather forecasting
Cost III, C(III)	- calculated assuming optimal utilization with no satellite weather forecasting
Cost IV, C(IV)	- calculated assuming optimal utilization with satellite weather forecasting

Since the size of the fleet will be adequate to transport the full production, the true benefit of satellite weather forecasting is [C(II)-C(I)] if no optimal utilization is to be done and the true benefit is [C(IV)-C(III)] if optimal utilization will be done. This assumes the cost savings will be passed on as lower prices. Thus we are using equation (1.7).

IV. The Data and the Results

The model problem was solved for three annual production levels - 730, 400, and 240 million bbl/yr. (or 2,1.1, and 0.66 million bbl/day, respectively) - the projected annual outputs in 1987, 1992, and 1997, Alaskan Oil [3]. However, the analysis was conducted by looking at only one quarter of the year and breaking it into 10 day periods. Using such a time reference was desirable because from an operational point of view similar weather conditions come in 5-10 day intervals rather than in month to month intervals. Also, the longer the time period considered, the less significant the fixed amount of storage becomes compared to the number of barrels to be shipped. These levels are based on an assumed total reserve in the North Slope field of 10 billion barrels and are uncertain because of uncertainties both in that total reserve and in the rate of consumption. The study by the Cabinet Task Force on Oil Import Control in Alaskan Oil [3] indicates that the field of "known" reserves will be entirely depleted by the year 2000.

The time scale has, of course, shifted since Alaskan Oil was written in 1970. Current indications are that production will begin in 1977 and reach its peak in the early 80's. The production curves in Alaskan Oil, therefore, have been shifted by five years.

The fleet composition in the Department of the Interior Report [6,p.60] has been adjusted. Present projections indicate a fleet of 13, 22, and 35 tankers in each of three successive phases. In 1985 the operation will be in phase 3 and the 35 tanker fleet will be broken down as follows:

Wt. class in thousand deadweight tons	45	60	70	75	80	90	120	130	150
# of tankers	1	3	2	3	2	2	16	5	1

In the 1990's when production levels will be dropping it was left to the computer program to eliminate the appropriate tankers since it is obvious that the model will consistently use the more efficient larger tankers when possible and will drop from the solution the smallest tanker when it becomes expendable.

It was assumed that the oil will be shipped to the three ports on the West Coast in the proportions projected by the Alyeska Pipeline Service Company (APSC) as quoted in DOI [6], namely:

15% to Juan de Fuca
35% to Coos Bay
50% to Santa Barbara

100% from Valdez

The possibility of shipping to other points (e.g. Japan, the East Coast via Panama or the North West Passage) was ignored.

Since industry sources indicate storage capacities of six to eight days production are desirable, storage at the origin and destinations were assumed to be seven times the level of daily throughput.

Valdez - 14 million (100%) = S

Juan de Fuca - 2.1 million (15%) = D_1

Coos Bay - 4.9 million (35%) = D_2

Santa Barbara - 7.0 million (50%) = D_3

Since there are antitrust considerations involved it was necessary to have the oil companies pass their estimates of the number of tankers they would be purchasing through independent auditors who then indicated only the sums for the resulting fleet. This means in terms of this model that optimization was done with respect to the whole fleet while individual oil companies will be optimizing with respect to their portion of the fleet. Thus, the benefit from better fleet utilization will be greater than what might actually be achieved, but the estimate of the extra benefit of satellite ocean condition forecasting information, which is what must be quantified in this study, will be accurate.

The relation between shipping costs and vessel sizes taken from Alaskan Oil [3, p. 72] are

Class (dwt)	Cost ($bbl/$10^3$ miles)
50	.14-.16¢
100	.10-.11
200	.07-.08

Fitting these by a polynomial we get the curve in Figure V. Since these were world tanker prices they must be doubled as recommended in the reference to reflect the fact that only American ships will be used. Also, since these were 1969 prices they must be inflated to 1974 prices. The inflation factor used was 45.6%, derived from the composite index of construction costs in the U.S. Department of Commerce's Survey of Current Business. (The cost of the tankers' construction is more than 50% of all costs in the long run, see [6, pp. 5-7].)

It was further assumed that the shipping costs would vary from period to period in roughly the same proportion as the average trip time to Juan de Fuca in each month as determined by ODS [4, p. 12]. The costs, therefore, ranged between 5% above and 4% below the yearly average cost. (This is a conservative range since the weather variation between ten day periods will be larger than the average variation from month to month.) The assumption also overcomes the problem of using representative weather figures for the year when the analysis is only done for one quarter of the year.

Since the operating costs of increasing of decreasing the barrels of oil in storage were found to be negligible these were assumed to be zero. While the model could be adapted to addressing the question of the optimum storage capacity investment, this was not done. It was assumed that the industry estimates given were fixed.

For the shipping capacity constraint the 16.0 knots speed of the modal ship in the fleet, the 120 K dwt tanker, was used to calculate round trips. Assuming 345 days running time and 21 days per year for routine maintenance and repair, 23 hours for turnaround time and 1,212 miles to Juan de Fuca, we get a maximum

$$\frac{345 \times 24}{2\ (1{,}212/16.0) + 23} = 47.45 \text{ round trip per year}$$

or 11.9 round trips per quarter of the year/per ship.

It is assumed by the model that the maximum round trips to the other two destinations are less in proportion to the distances (which were 1,452 and 2,028 miles, respectively). The fleet can be expected to make 34.6 round trips maximum per ship over one year using the weighted distance to the three ports according to Ocean Data Systems assumptions [4]. ODS performed a computer simulation which used tanker weather log data from 1948 to the present and varied the speeds of the tankers in accordance with the weather conditions reported in the log and found that the weather simulated delays permitted only 29.2 round trips [4]. However, this 15% loss cannot be fully avoided because there will be bad weather at all points along the route occasionally. Thus the maximum saving possible was assumed conservatively to be 12% (i.e., $\theta = .12$ as an upper bound) or 4.4 round trips.

Following the estimate of ODS, it was assumed that the achievable gain in shipping capacity due to satellite information was 50% ($\theta = .06$) of the total potential capacity gain, i.e., 2.2 round trips saving was used.

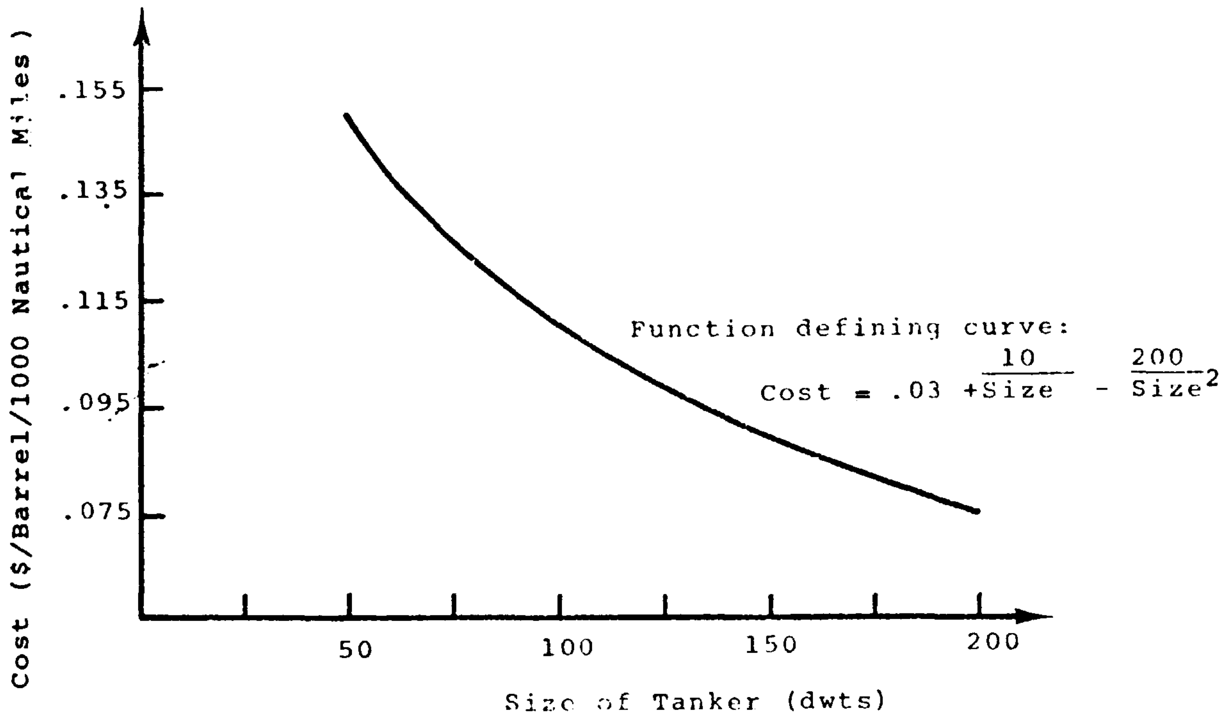

Figure V Cost of Transporting Oil on Alaskan Marine Link (1969 Dollars)

Using the cost figures in section 5.1 of [5] for the 120 K dwt tanker, the time loss of 12% (6% when using satellite information), the assumption that self insurance is equal to paid premiums, and the assumption that 30% of all damage is weather related, we get a maximum potential cost saving (δ) of

Amortization	58.0	
Other Operating Costs	33.8 x .12 =	4.06%
Insurance	9.2 x .12 x .30 =	0.33%
	100.0	4.39%

approximately 4.4% (δ = .044) at maximum

It is assumed only half of this, also, may be captured. Therefore, δ = .022 when satellite information is used.

The simulation procedure of estimating the yearly benefit as [C(IV) - C(III)], as presented in the previous section, was followed. The undiscounted results are presented in Table III.

It was assumed that benefits could be fully captured beginning in SEASAT's first full operation year (1985) due to the unusual set of factors which favors this:

- all U.S. ships required by Jones Law
- close government supervision and possible regulation
- a weather routing procedure already in operation today
- environmental concern

Table III Benefit to Alaskan Oil Marine Link ($ millions 1974)	1987	1992	1997	1985-2000
Case Study Benefits [C (IV)-C(III)]	14.5	4.5	2.9	110.2
C (III) - No satellite but optimal tanker utilization	166.67	190.90	112.43	
C (IV) - Use of satellite and optimal tanker utilization	152.20	186.60	109.54	

The program was solved for 1987, 1993, and 1997 and the rest of the figures were interpolated or extrapolated from these.

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[3] ______________, ed., Alaskan Oil, Costs, and Supply, New York: Praeger Publishers, 1971.

[4] Ocean Data Systems, TAPS SEALEG STUDY, Monterey, California, May 30, 1974. (Unpublished study summarized in section 7.4.1 of reference [5].)

[5] SEASAT Economic Assessment, Study for the Office of Application, National Aeronautics and Space Administration, Contract NASW-2558, by ECON, Inc. Princeton, New Jersey: ECON, Inc. October 1974.

[6] U.S. Dept. of Interior, Final Environmental Impact Statement Proposed Trans - Alaska Pipeline, Introduction and Summary, 1972.